

RX113 Group

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Design Guide for Renesas Touch Solution

Summary

The RX113 group has incorporated hardware (Capacitive Touch Sensor Unit; CTSU) that detects human body contact by measuring capacitance existed between touch electrode and human body.

This application note introduces the principle of capacitive touch detection as well as explains the detail of current-frequency conversion system that is used in RX113.

Target Device

RX113 Group

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1. Introduction

A capacitive touch switch using the capacitance generated between human body and touch electrode is widely used for home appliances, AV equipment, automotive, and industrial equipment including smart phones. An example of a product using capacitive touch is shown in Figure 1-1. The surface is covered with a uniform plastic and there is no projections or cutouts in the design. The “switch” is defined by characters which are highlighted using LED backlighting. The touch switch is robust as there are no mechanical parts and it is much simpler than mounting a physical switch into the curved surfaces. The touch technology also allows detection of finger movement so sliders, wheels and simple keypads can be implemented. This is difficult to achieve by the conventional switch.



Figure 1-1 Product example of capacitive touch switch

This application note introduces the basis of capacitive touch, the detail of capacitive touch switch detection of Renesas' original system, and examples of capacitive touch switch with our system.

2. The Basic of Capacitive Touch Switch

The capacitive touch switch is different from the popular switch that has the electrical contact since it detects the status of the switch (ON or OFF) by measuring a small capacitive (1pF or less) change created when the human body comes close to the electrode. There are several ways to measure the capacitance and convert it to the status of switch. The easiest way is called a relaxation oscillation method which forms a low-pass filter (LPF) using capacitance and resistance. When the human body changes the capacitance there is a change in timing of the LPF. This method is widely used because the circuit is simple and the special capacitance measurement circuit is not necessary. However, it is vulnerable to noise in general and can be affected by inverter noise generated from appliances and lighting equipment. The capacitive touch detection method which Renesas has developed adopts the switched-capacitor filter in order to achieve both high sensitivity and noise immunity. The method determines the status of switch by converting the capacitance to current, amplifying and digitizing. (Figure 2-1)

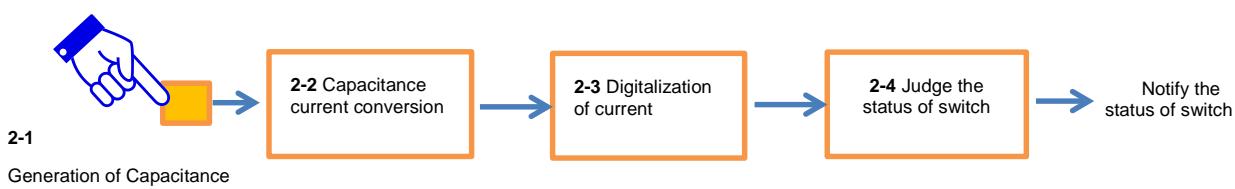


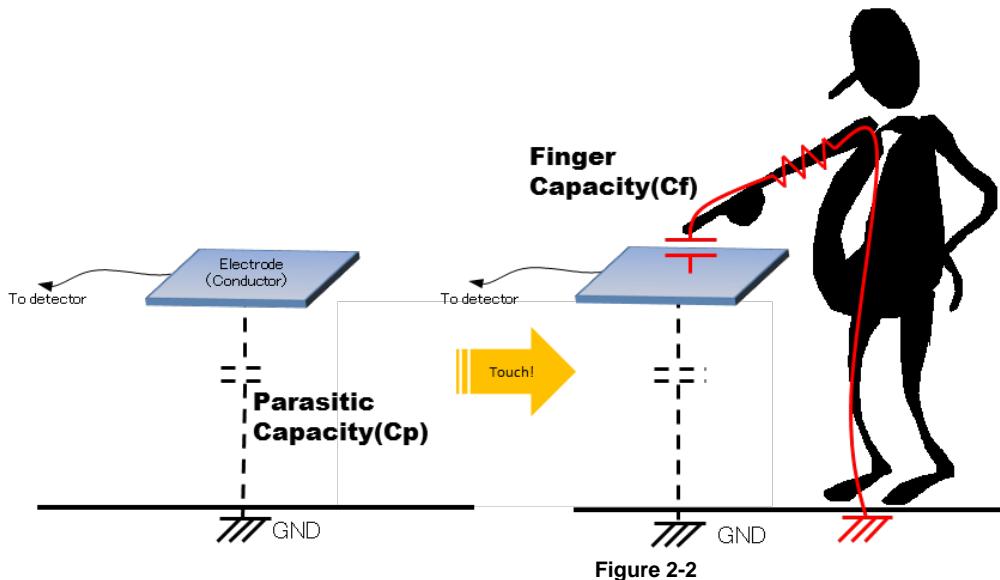
Figure 2-1

Flow of capacitance touch switch detection (number-number is the chapter number)

The basic of capacitance touch switch detection is described in this chapter in accordance with the flow of Figure 2-1.

2.1 Generation of Electrostatic Capacity

The concept of sensing electrostatic capacity is shown in Figure 2-2. Parasitic capacity (C_p) exists between an electrode in the space and the conductive materials (ground pattern or metal frame etc.) of its surroundings. When a person interacts with the electrode the finger capacity (C_f) is generated between the human body and electrode. The body acts as an additional capacitance between the electrode and ground. (The red line in the figure)



Generation of electrostatic capacity (self-capacitance method)

The resulting total capacitance is the sum of the parasitic capacitance and the finger capacitance as shown the following equation.

$$\text{Total Capacity} = C_p + C_f$$

The capacitive touch switch periodically measures the total capacitance of the electrode circuit and detects the increase C_f of capacitance created by human body.

This detection method is referred to as the self-capacitance method. It consists of a single electrode. The shape of electrode is also simple and circuit configuration can be implemented relatively easily. However, it is necessary to consider the layout and circuit configuration to reduce Parasitic Capacity as much as possible since C_f is very small and as C_p becomes large it is difficult to detect the small change in the overall value.

A second method of sensing capacitance is the mutual capacitance method. With this method a pair of electrodes are used in contrast with the self-capacitance method with a single electrode. An example of mutual capacity method is shown in Figure 2-3. The mutual capacity method is configured using a receiving electrode, transmitting electrode, and pulse generators. When pulses are sent to the transmitting electrode energy is transferred by field coupling to the receiving electrodes. If a human body approaches part of the electric field moves to the human body and the electric field between electrodes decrease.

It is possible to detect the approach of a human body by measured the decrease in energy couple to the receiving electrode. The circuit of the mutual capacity method is more complicated than self-capacitance method. However, it is possible to decrease the influence of parasitic capacity, which is a problem in a self-capacitance method, and also possible to increase the strength of electric field generated which provides highly sensitive detection. A key application is for touch screens.

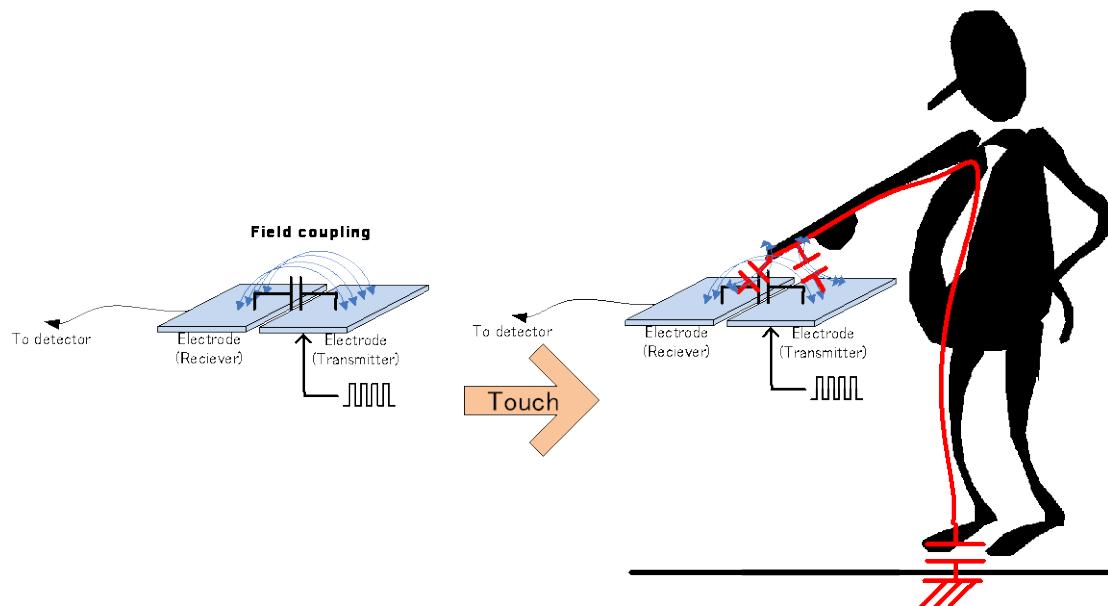


Figure 2-3

Mutual capacity method

2.2 Capacitance-Current Conversion

A Switched capacitor filter (SCF) is used to convert the capacitance described in the chapter 2.1 to a current that is proportional to that capacitance. The SCF is created using a capacitor, power, two switches and the control signal to toggle two switches ON/OFF alternatively.

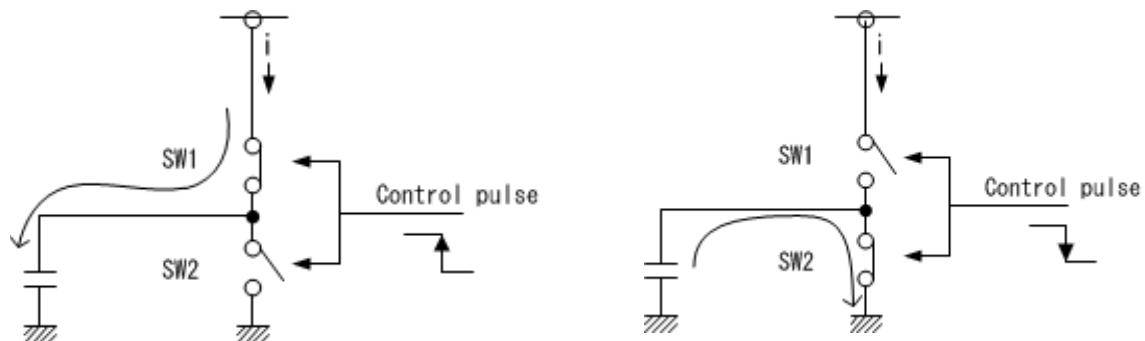


Figure 2-4
SCF configuration and Charge and discharge operation of capacitor

SW1 and SW2 are controlled by the pulse so when one turns ON and the other turns OFF. When SW1 turns ON and SW2 turns OFF, the capacitor is charged as described in Figure 2-4 (left). After switching SW1 to OFF, SW2 to ON, the capacitor is discharged as described in Figure 2-4 (right).

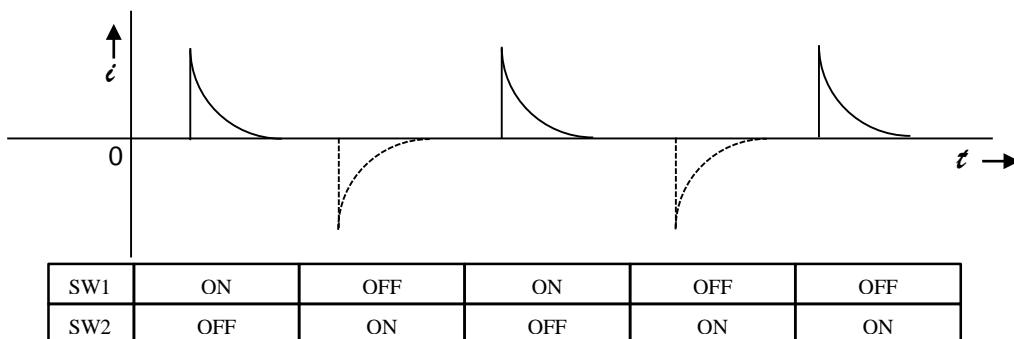


Figure 2-5 the status of SW1 and SW2 and the relationship of electric current i

Figure 2-5 shows the status of SW as they are repeatedly turning ON and OFF and the relationship of current i in the circuit. The electric charge of the capacitor is 0 at the moment SW1 turns ON and the current flows into the capacitor rapidly. As the charge of the capacitor progresses, the current decreases, and the current stops at full of charge. After that, the electric charge of the capacitor flows into the ground when SW2 turns ON. This current (Figure 2-5 dashed line) does not appear on the power supply side because SW1 turns OFF. When this cycle repeats, a certain amount of current flows intermittently synchronized with turning ON and OFF.

If the capacitance of the circuit is doubled while the switching frequency remains the same the current will also be doubled. (Figure 2-6). If the capacitance is maintained the same but the switching frequency is instead doubled the current will also double. (Figure 2-7)

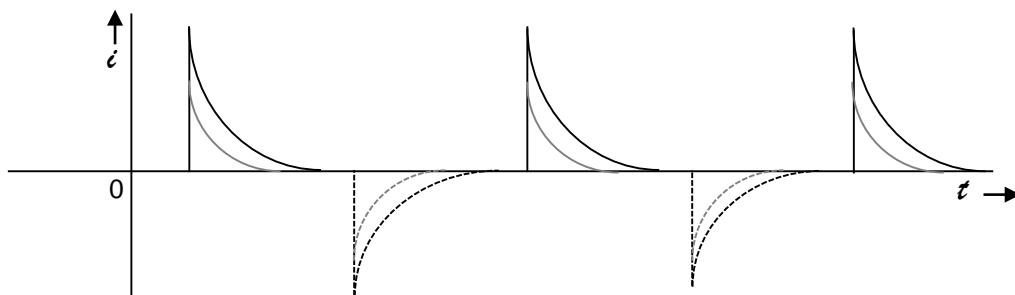


Figure 2-6 double external capacitor capacity

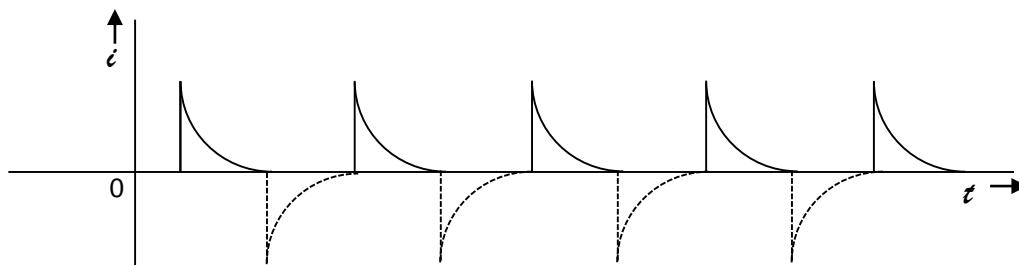


Figure 2-7 double SW switching frequency

The following equation describes the relationship between the circuit current as i , the switch frequency as f , capacitor capacity as c , and circuit voltage as v .

$$i = fcv$$

In this case, if f and v are constant, i is proportional to c . This is the basic principle used to convert capacitance changes caused by human approach to changes of current. The conversion ratio of capacitance and current can be changed by adjusting f and v .

2.3 Digitizing of Current

The capacitance which is converted to current is digitized by a circuit that changes oscillating frequency in accordance with current and a counter that counts the pulses output from the oscillator circuit.

The flow of digitizing process is shown in Figure 2-12. The electric current alternates because the capacitor in the SCF charges and discharges continually. This alternating current is smoothed by the power supply circuit connected SCF. The current is sent to the current oscillator that varies oscillation frequency in proportion to current. The output of the oscillator is sent to the counter. The counter counts the number of pulses during a specified time. The graph in the figure shows an example when the frequency of SCF is fixed and the capacitance value is doubled, the current and the frequency of current oscillator double. The resulting count value measured by counter also doubles, from 6 to 12 in this example.

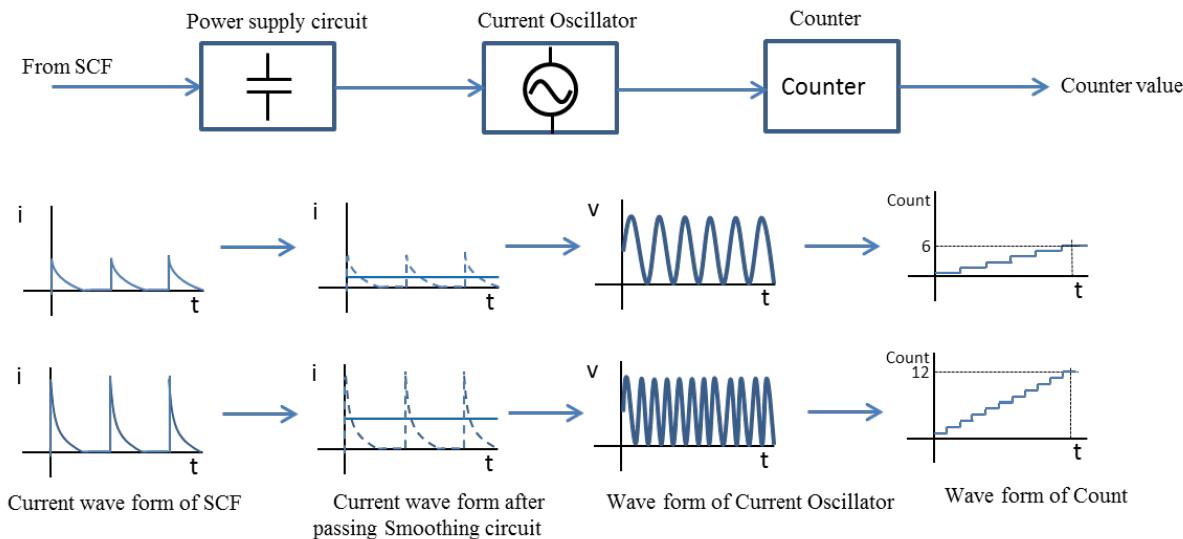


Figure 2-8 Flow of current digitization

2.4 ON/OFF switch judgment

As explained in chapter 2.1, for self-capacitance method, it is possible to judge the increase of capacitance when human body has touched, or is close, to the electrode. This is done by regularly performing the capacitance measurement process described above and measuring the changes of the counter value.

The process flow of deciding whether a switch is ON/OFF when finger approaches the electrode and then moves away again is shown in Figure 2-9. Measurement of the capacitance is carried out at a regular interval as shown in the figure. The count value obtained by the measurement is steady when finger is away from electrode as shown by the blue line on the graph. The count value increases when finger is approaches, and decreases to a steady value when the finger is away again. The count value when finger is not close to the electrode is used as a reference value (green dashed line) and a threshold value is calculated as a specified difference from that reference value. The decision of ON/OFF can then be simply determined by checking if the actual count value exceeds the threshold value and switching OFF when the value is under the threshold value. Typically, the OFF decision also requires that the value goes below the threshold by a specified amount referred to as the hysteresis.

Sensitivity adjustment of the capacitive touch switch can be done by changing the threshold value. Chattering suppression of the switch and the reaction rate can be adjusted by changing the cycle of measurement timing and

averaging multiple count values. More detail on this is described later.

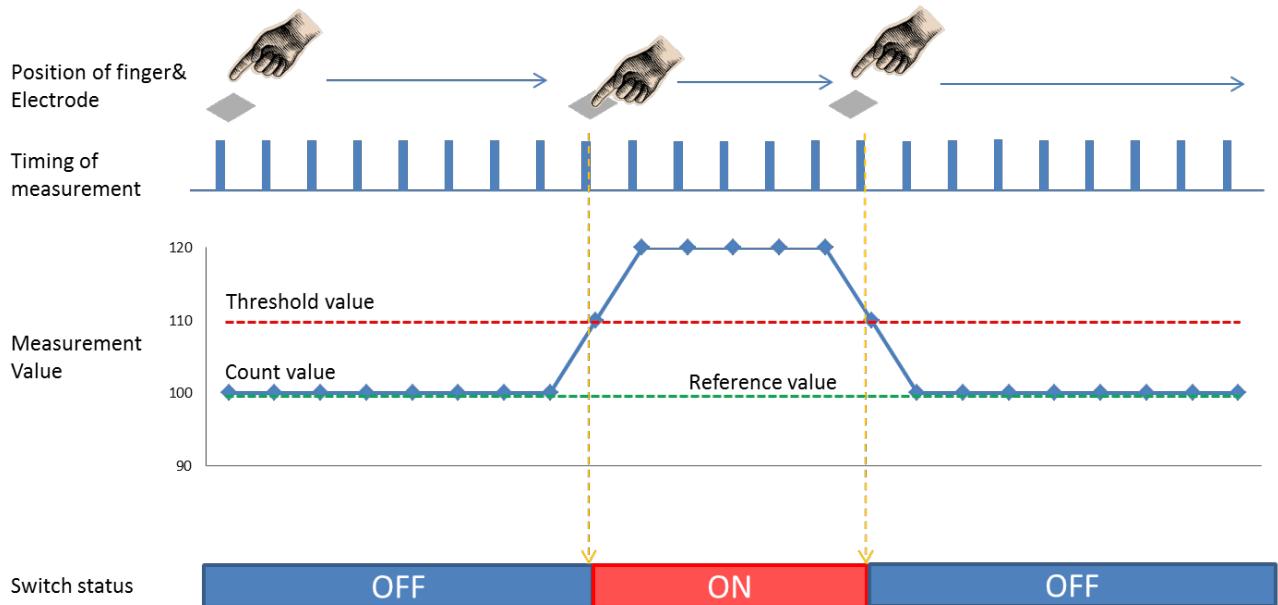


Figure 2-9 ON/OFF switch judgment

3. The Capacitive Touch Detection System of Renesas

Renesas's capacitive touch detection system has both high sensitivity and high noise immunity provided by the CTSU (Capacitive Touch Sensing Unit). The CTSU has analog circuitry for capacitance detection that has low impedance and high sensitivity. The analog front end is coupled with an analog-digital conversion circuit that achieves excellent temperature characteristic and linearity. The solution includes a Capacitive touch API (Application Program Interface) utilizing the 32 bit CPU high speed and high efficiency that facilitates the development of capacitive touch system without user needing to fully understand operation of the hardware. These hardware and software features are explained in this chapter.

3.1 Overview

An overview of Renesas's capacitive touch detection system is shown in figure 3-1. The system is divided into a hardware layer and a software layer.

The Hardware layer includes:

I/O Driver - the driver connects directly to touch electrodes and converts the capacitance to electric current created by the pulse drive,

Analog Front End (AFE)- converts the electric current to frequency

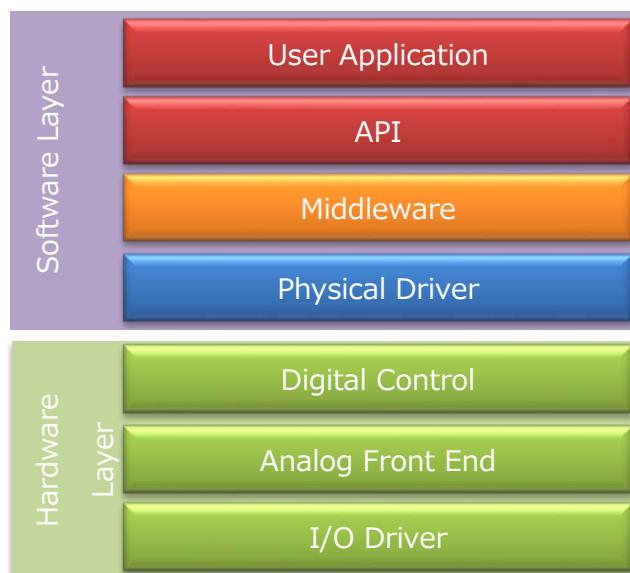
Digital Control – controls the I/O driver and AFE blocks to convert the capacitance to a digital value that is then passed to the software .

The Software layer includes:

Device Driver that controls hardware configuration and operation

Middleware API that performs touch detection and determination of finger position on a slider or wheel

Middleware API provides interface to User application



3.2 Hardware

3.2.1 Overview

An overall view of hardware is shown in figure 3-2. The hardware is divided into I/O Driver, Analog Front End, Digital Control, and CPU. Basic operation is as follows.

- 1) The current output from the I/O Driver changes when a finger approaches an electrode which is connected to I/O Driver. Only one I/O Drivers is active at a time and the drive pulse signals are switched sequentially. There is a single Pulse Generator but multiple I/O drivers are used to measure multiple electrodes.
- 2) I/O Driver current is smoothed by an external low pass filter (LPF) and sent to the current controlled oscillation circuit (ICO) which converts changes in current to changes in frequency.
- 3) The Digital Control circuit counts the pulses from the ICO for a specified period of time. This count value, which is proportional to the capacitance, is then stored in a register.
- 4) The count value is automatically transferred to RAM through data transfer circuit (DTC). A measurement completion interrupt is sent to CPU at the same time as the data transfer. The software reads the count value and processes the data to provide touch detection or position on the wheel or slider.

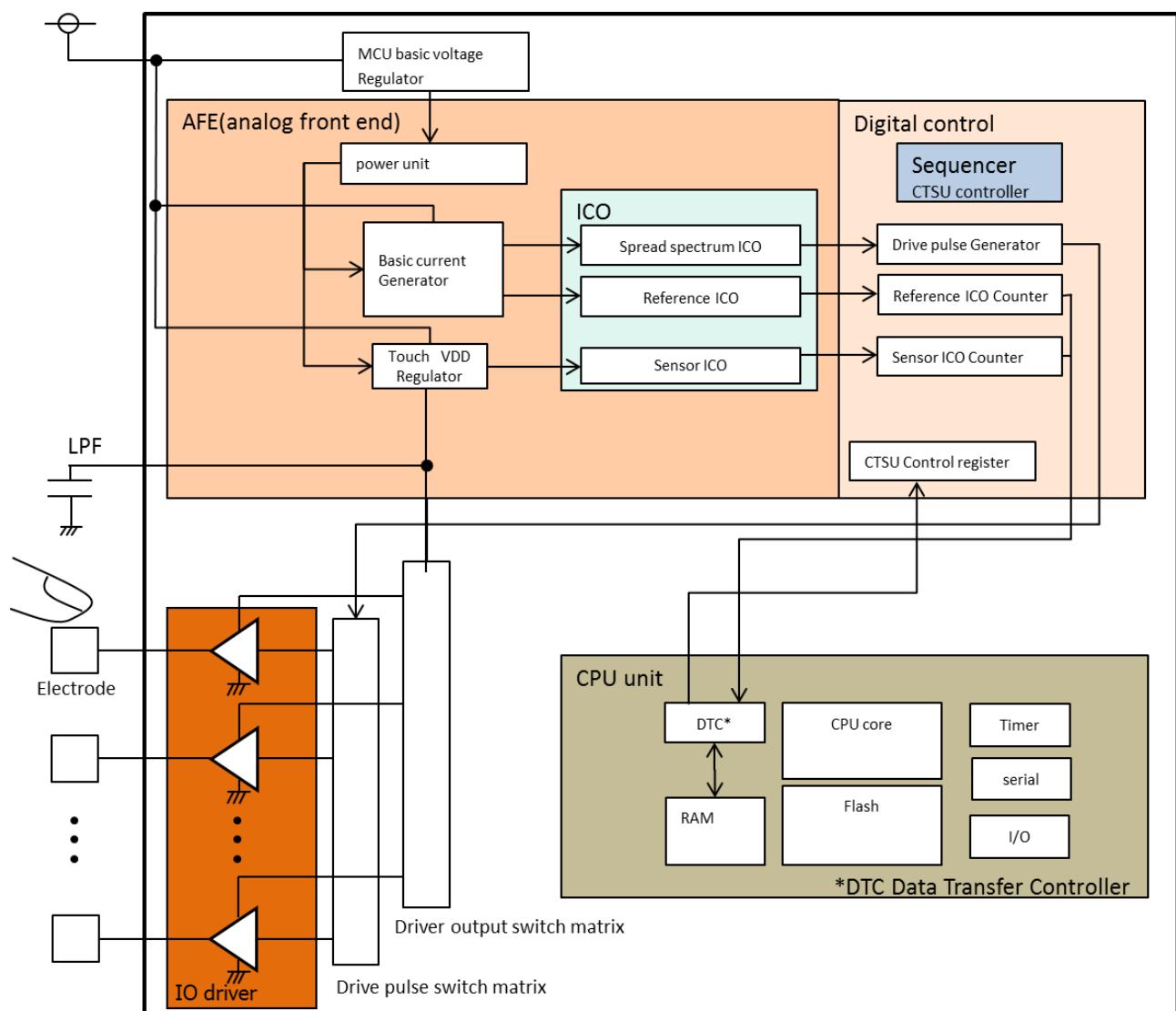


Figure 3-2 overall view of hardware

3.2.2 I/O Driver & Drive pulse generator

The structure of I/O Driver is shown in figure 3-3. The I/O Driver consists of a two pair of switches controlled by drive pulse supplied from the Digital Block. The signal from the driver pulse generator results in the switches alternating between open and closed. In accordance with previously presented equation ($i=FCV$), the resulting current is dependent on the voltage that is supplied from Touch VDD regulator, capacitance of the electrode, and frequency of drive pulse. This current is smoothed through LPF and sent to ICO in the Analog Front End part.

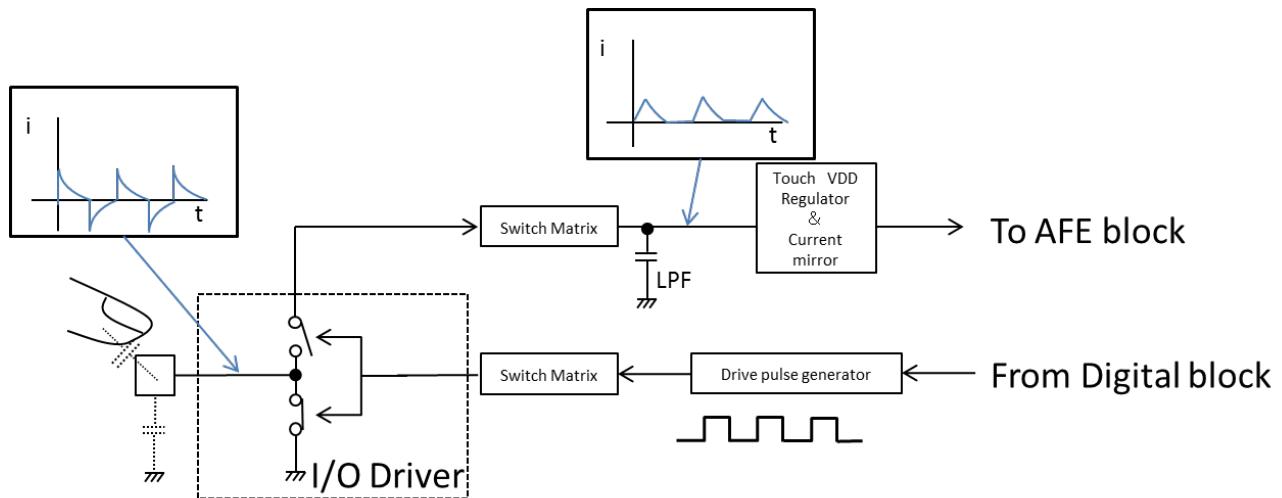


Figure 3-3 diagram of I/O Driver

3.2.3 Analog Front End

The structure of AFE is shown in figure 3-4. AFE primarily consists of a power generation part and ICO part. The capacitance that is converted to current in I/O Driver part is converted to frequency in AFE part, and sent to Digital control part.

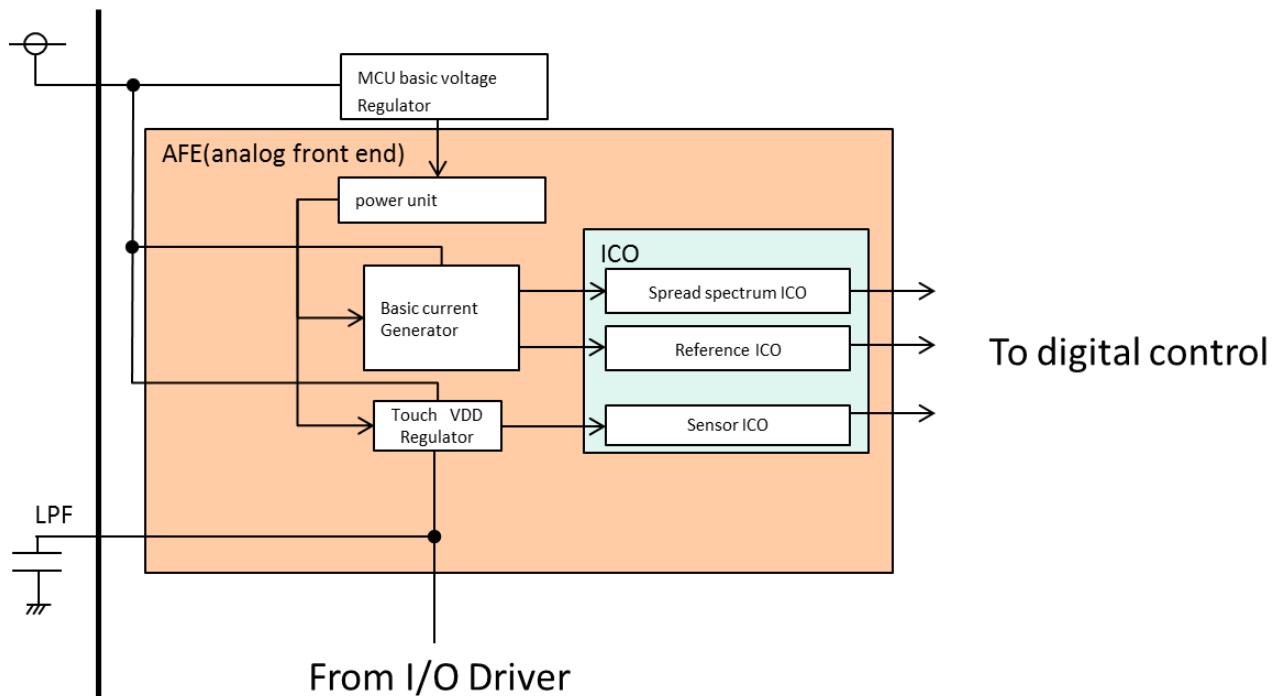


Figure 3-4 Analog Front End

(a) Touch VDD regulator & Sensor ICO

The structure of Touch VDD Regulator is shown in figure 3-5. Touch VDD Regulator is structured by Voltage Regulator that supplies voltage to I/O Driver, Current offset to offset the detected electric current, and current mirror that passes electric current to ICO part. ICO is an oscillator that changes oscillating frequency depending on the input electric current, and increases the number of frequency in proportion to the increase of the current.

Current offset is a mechanism to offset the amount of electric current in order to reduce the influence of the parasitic capacitance included in the current that is measured as an electrostatic capacitance. Detail is described later.

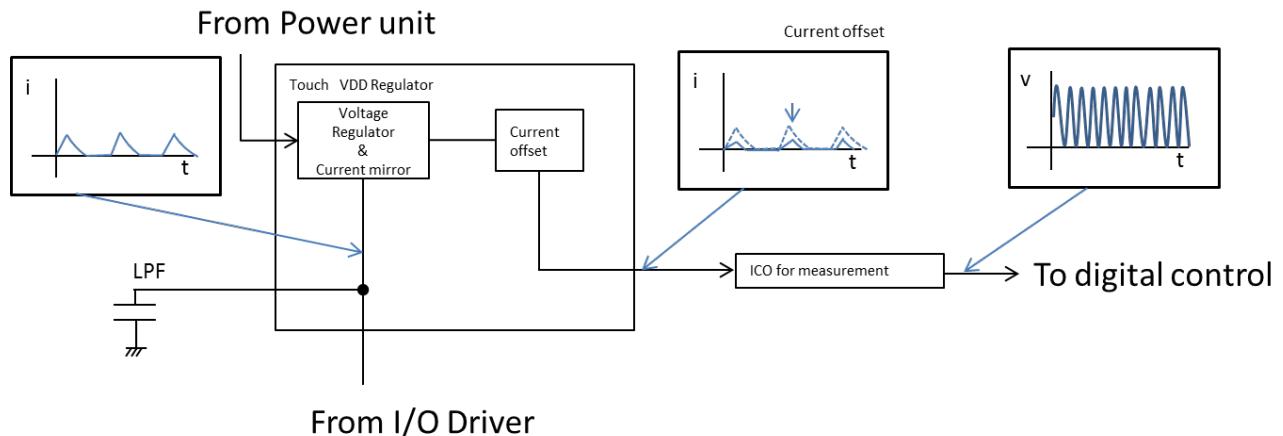


Figure3-5 Touch VDD Regulator & Sensor ICO

(b) Basic current generator, Reference ICO & ICO for spread spectrum

The structure of Basic current generator, Reference ICO, and Spread spectrum ICO is shown in figure 3-6. These two ICO differ in a role. The pulse generated in Spread spectrum ICO is eventually sent to I/O Driver and used for frequency diffusion of drive pulse of SCF. The other Reference ICO is used for comparison of Sensor ICO which is mentioned above. Detail of how to use is described later respectively.

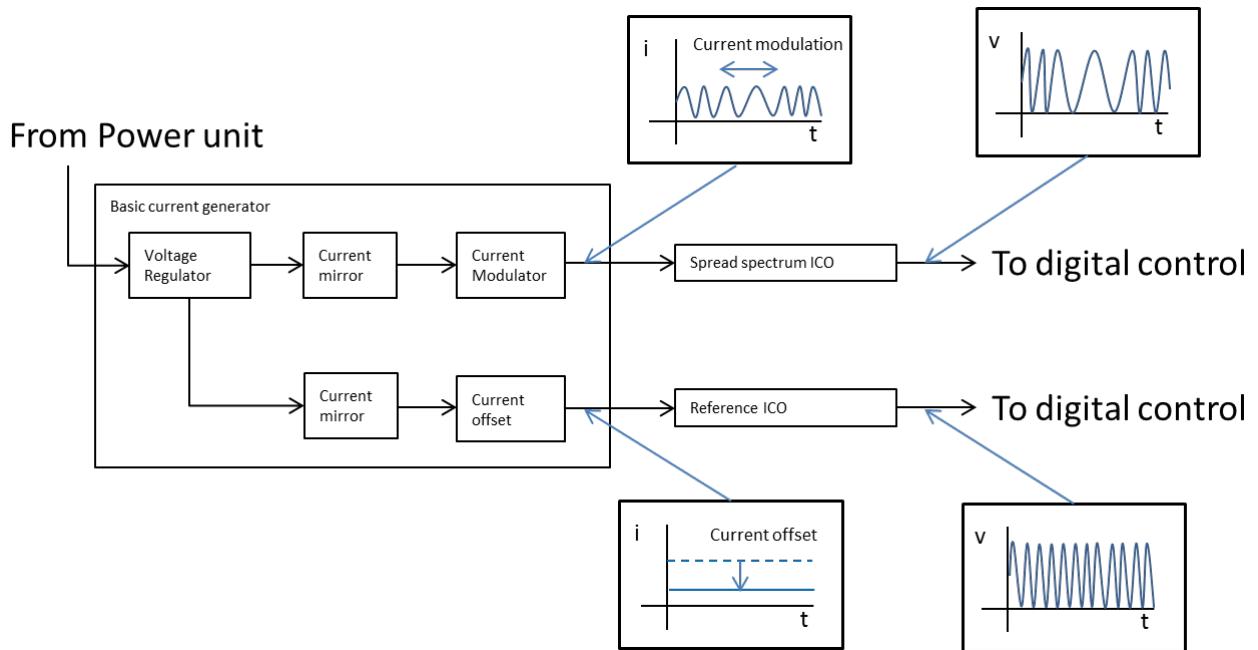


Figure3-6 Basic current generator, Reference ICO & for spread spectrum

Basic current generator is structured by Voltage Regulator to supply electric current with a constant voltage, and Current Modulator and Current Offset that supply controlled electric current to ICO through Current mirror. Voltage Regulator is the same as the structure of Voltage Regulator in Touch VDD Regulator above, and supplies a constant voltage to subsequent current through Current mirror. Current modulator modulates electric current outputting from

Voltage Regulator in order to diffuse frequency of subsequent ICO for spread spectrum. As shown in the graph of figure 3-6, as a result, waveform that ICO for spread spectrum output is modulated to FM and sent to Drive pulse generator of Digital control part. Current Offset controls the output frequency of subsequent Reference ICO by restricting the current output from Voltage Regulator.

3.2.4 Digital Control & CPU unit

Digital control and CPU unit is shown in figure 3-7. Digital control is structured by counter to count output pulse of ICO, Drive pulse generator to generate drive pulse of I/O Driver based on FM modulation pulse of ICO, and Sequencer to control sequence operation for whole CTSU and Register group to exchange the data with CPU. CPU unit exchanges the data with CTSU through DTC (Data Transfer Controller) or Register and execute a process involved in the touch switch in accordance with algorism of software.

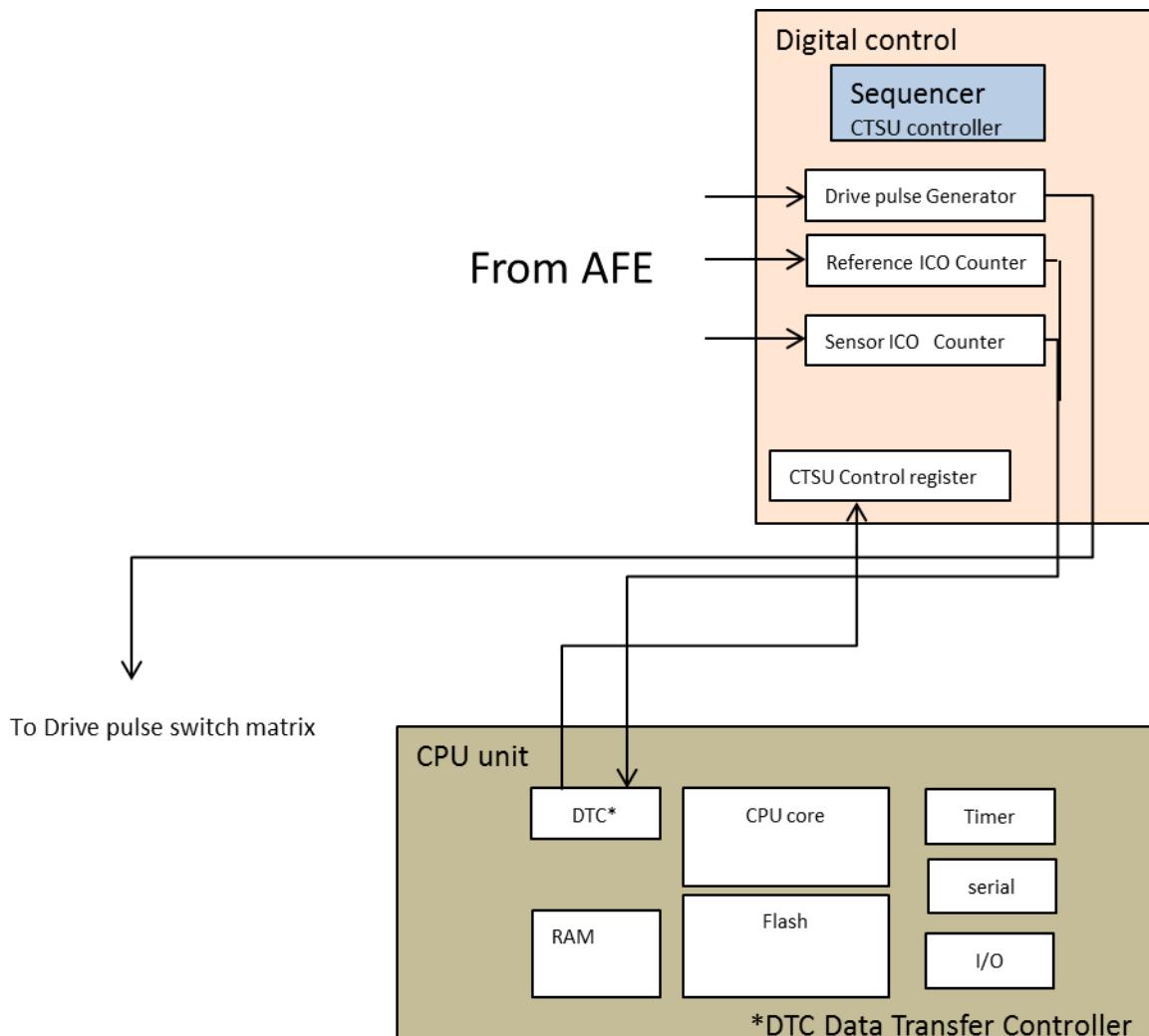


Figure3-7 Digital control & CPU unit

(a) Drive pulse generator

The structure of Drive pulse generator is shown in figure 3-8. Drive pulse generator is structured by Clock pulse generator, Phase shifter, Polynomial counter, and Mixer. Input from CPU oscillator is divided to an appropriate frequency in Clock pulse generator and sent to Phase shifter. Phase shifter follows the instruction from Polynomial counter and inverts the phase. Polynomial counter is controlling to randomize the phase of pulse output from Phase shifter based on the pseudorandom number and generating polynomial. Output from Phase shifter is normalized by FM modulation output of ICO for spread spectrum and randomized the cycle. Pulse output that was randomized for both phase and cycle is sent to I/O driver, and randomize the switch timing of I/O Driver. In this way, the purpose of Drive

pulse generator is to spread the cycle and phase of SCF switch timing in I/O Driver, control the synchronization of exogenous noise and switch timing, and protect the influence to touch detection. The detail is described later.

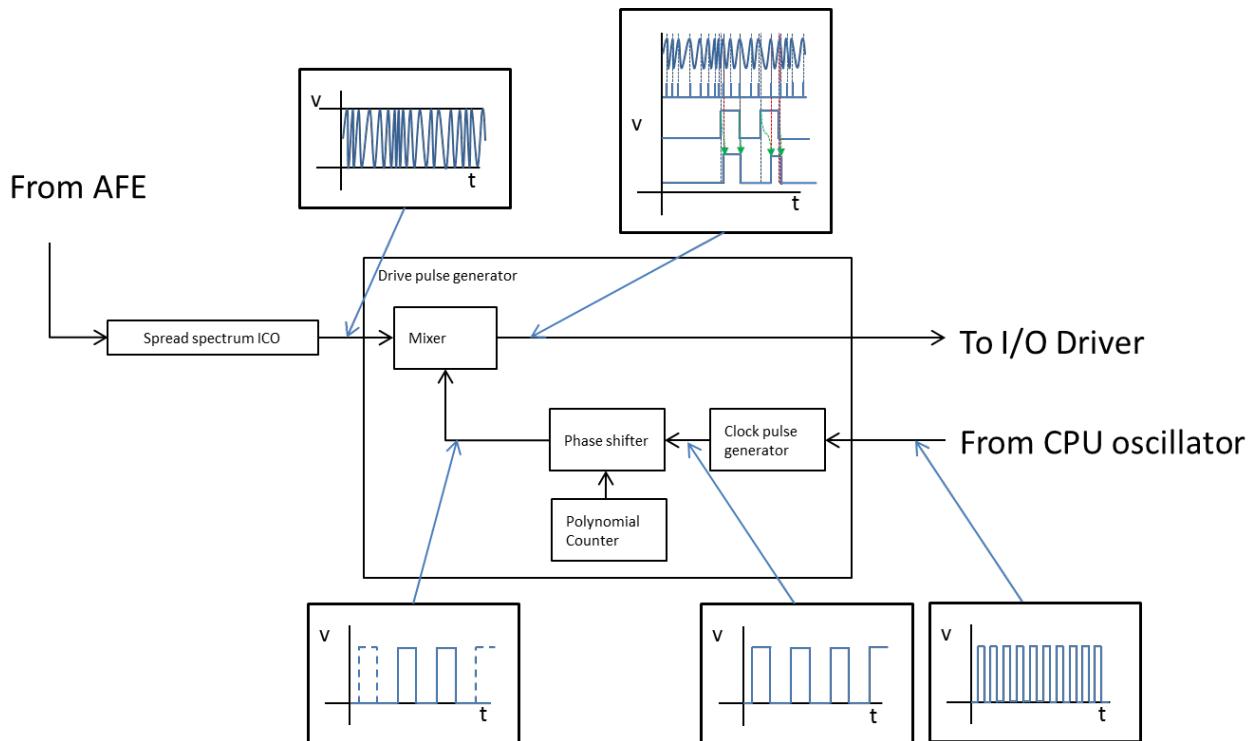


Figure 3-8 Drive pulse generator

(b) Reference counter & Sensor counter

The structure of Reference counter and Sensor counter is shown in figure 3-9. These counters are controlled by Sequencer and count the pulse outputting from ICO for a certain time. The count value is transferred to RAM of CPU unit through DTC. The count value transferred to RAM is eventually processed by the software and be able to detect the changes of capacitance, that is, contact of the human body.

From AFE

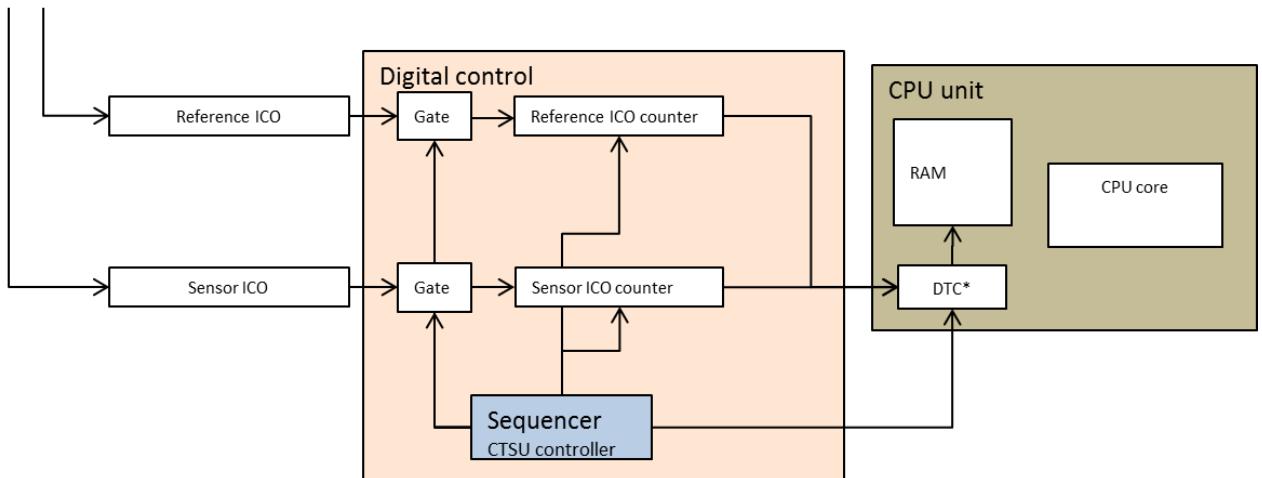


Figure 3-9 Reference counter & Sensor counter

3.3 Firmware

3.3.1 Overview

An overview of the software is shown in figure 4-10. The software consists of Physical Driver, Middleware, API, and Application. The Physical Driver exchanges data directory with CTSU and exchanges the data with upper layer. The Middleware processes the ICO value obtained via Physical Driver and passes it to API. It also passes commands specified by the upper layer to Physical Driver. The API coordinates the exchange of data between Application layer and Middleware layer. The Application processes the data to determine status of touch key, slider, and wheel. It returns ON/OFF status of the key and the finger position on the slider and wheel depending on the request of User Application. Also, it includes the debugger interface to connect with the capacitive touch integrated development environment “Workbench6” and USB interface.

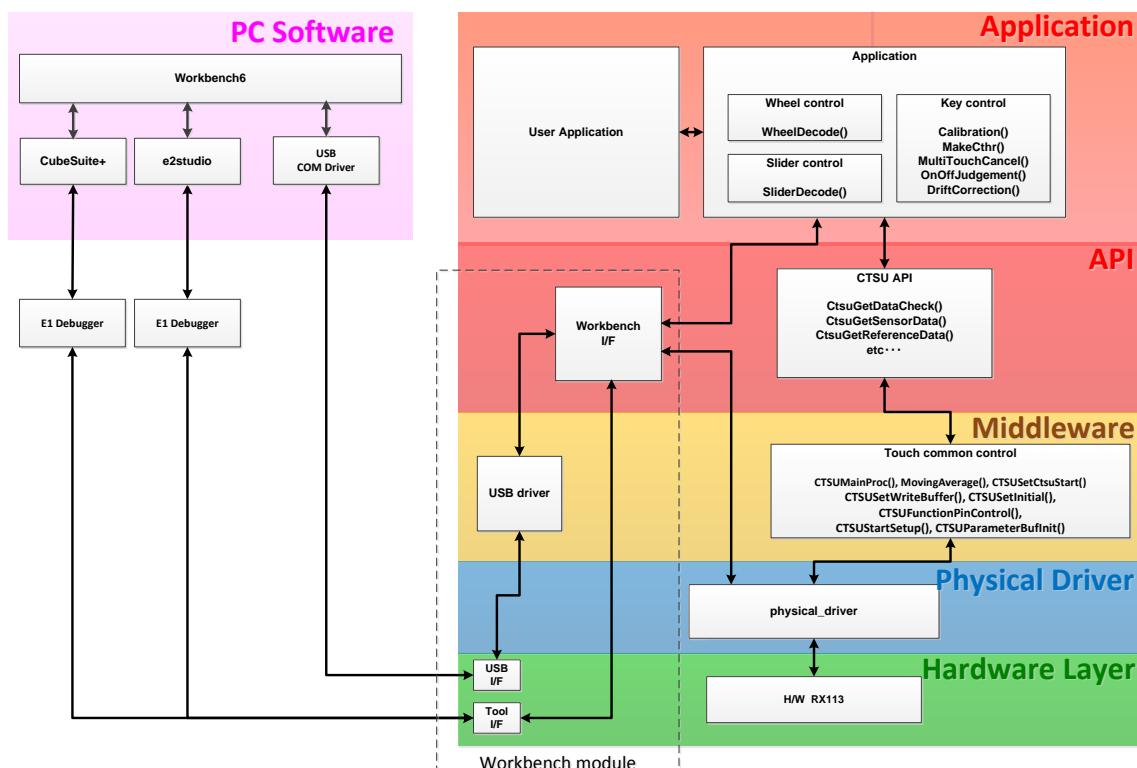


Figure 3-1 Overview of the firmware structure

3.3.2 Physical Driver

The Physical Driver provides the functions to access all the registers of the CTSU. It reads out and returns the data from the registers in order to respond to the request from upper layer. Also, it receives the write requests from upper layer and writes the value to the register.

3.3.3 Middleware

Middleware provides initialization of CTSU (including the DTC initialization for transferring the CTSU register value), averaging of ICO value, and register setting.

3.3.4 API

API provides functions to exchange the data between Application and Middleware.

- CTSU measurement mode setting API
- CTSU measurement data acquisition confirmation API
- CTSU sensor ICO measurement data acquisition API

For the detail of the see the application note

3.3.5 Application

The Application provides touch key, slider, and wheel processing. It performs the following processing from data that was collected by API.

- Calibration processing
- Follow-up correction processing of measurement data to environmental changes
- ON/OFF processing of the key
- Detection processing of slider and wheel position
- User's applications such as system control of the product and display of LED and LCD.

4. Designing a Touch Board and System

4.1 Overview

This chapter shows how to construct Cap touch key with CTSU. Overall order is as follows.

- Design of Cap touch key board
- Preparing the firmware for Cap touch
- Tuning the sensitivity of Cap touch key
- Evaluation (including the noise immunity test)

4.2 Design of Cap touch board

4.2.1 Design of the self-capacitance method Cap touch key board

(a) Basis of the capacitance

Figure 4-1 shows the capacitance model. The capacitance defined by the following formula:

- It is proportional to electrode surface area A.
- It is proportional to the relative permittivity κ of the inter-electrode material.
- It is in inversely proportion to the distance of inter-electrode.

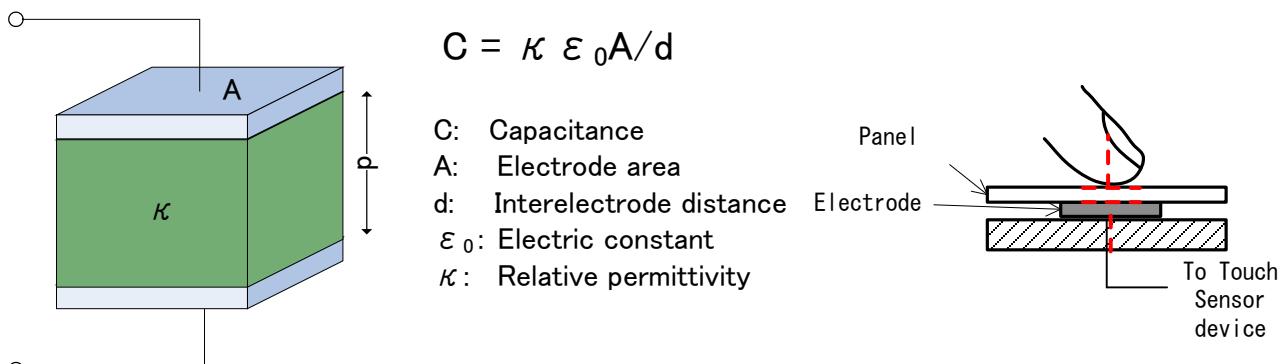


Figure 4-1 Capacitance model

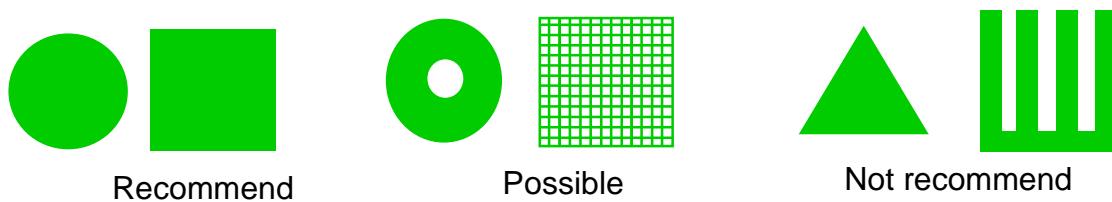
Capacitive touch detects the touch of the human body using these characteristics. A capacitive touch detector measures the capacitance between the human body and the electrode as shown Figure 4-1. Higher sensitivity and noise immunity is provided by a bigger capacitance difference between non touch and touch. A large sensor area will provide improved accuracy of the touch detection and high noise immunity. However, the increased sensitivity is also related to the touch area of the finger and it is not effective to increase surface area of the electrode past some value. The inter-electrode distance depends on thickness of the material with which the surface of the touch key is covered. Table 4-1 shows the relative permittivity of some common materials. It is different according to each material. Glass has the best relative permittivity excluding water. Acrylic and plastic are also often used.

Table 4-1 the relative permittivity of some common materials

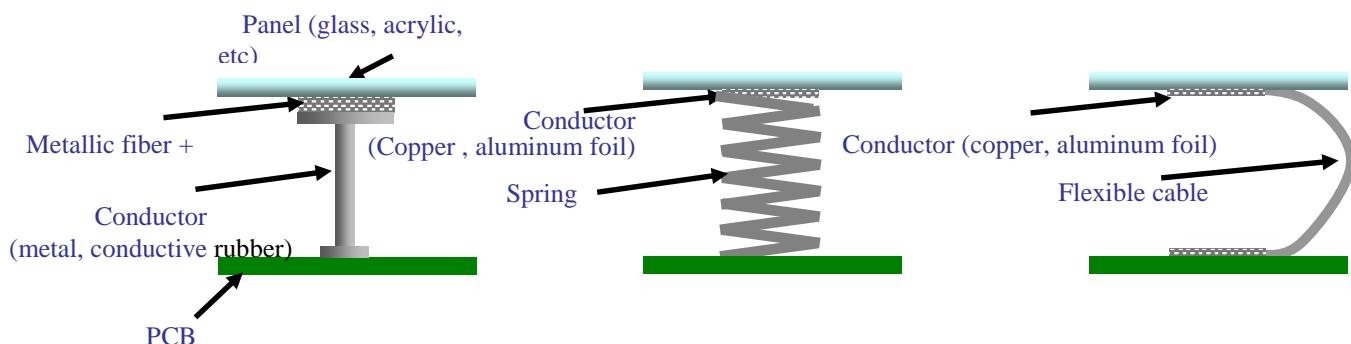
Dielectric Material	<i>k</i>
Acrylic	2.4-4.5
Glass	4.5-7.5
Nylon Plastic	3.0-5.0
Flexible Vinyl Film	3.2
Air	1.0
Water	80

(b) Electrode shape

The recommended size of the electrode is in forms of • or ■ with an area of 10mm×10mm to 15mm×15mm. A triangular, ▲, or E-shape pattern is not recommended since the electrode acts as antenna, and can be easily affected by noises. Lighting with LED lights from the back of the electrode is also effective when it is formed in a donut-shape or mesh configuration. However, in those forms, the sensitivity of the electrode can be weakened due to decreased area or noise can be created by the PWM control of LED. The preferable area of the electrode is equal or up to twice the size of area as the point of finger contact. Electrode sizes larger than twice the size of a finger can add parasitic capacitance that may lower the sensitivity.

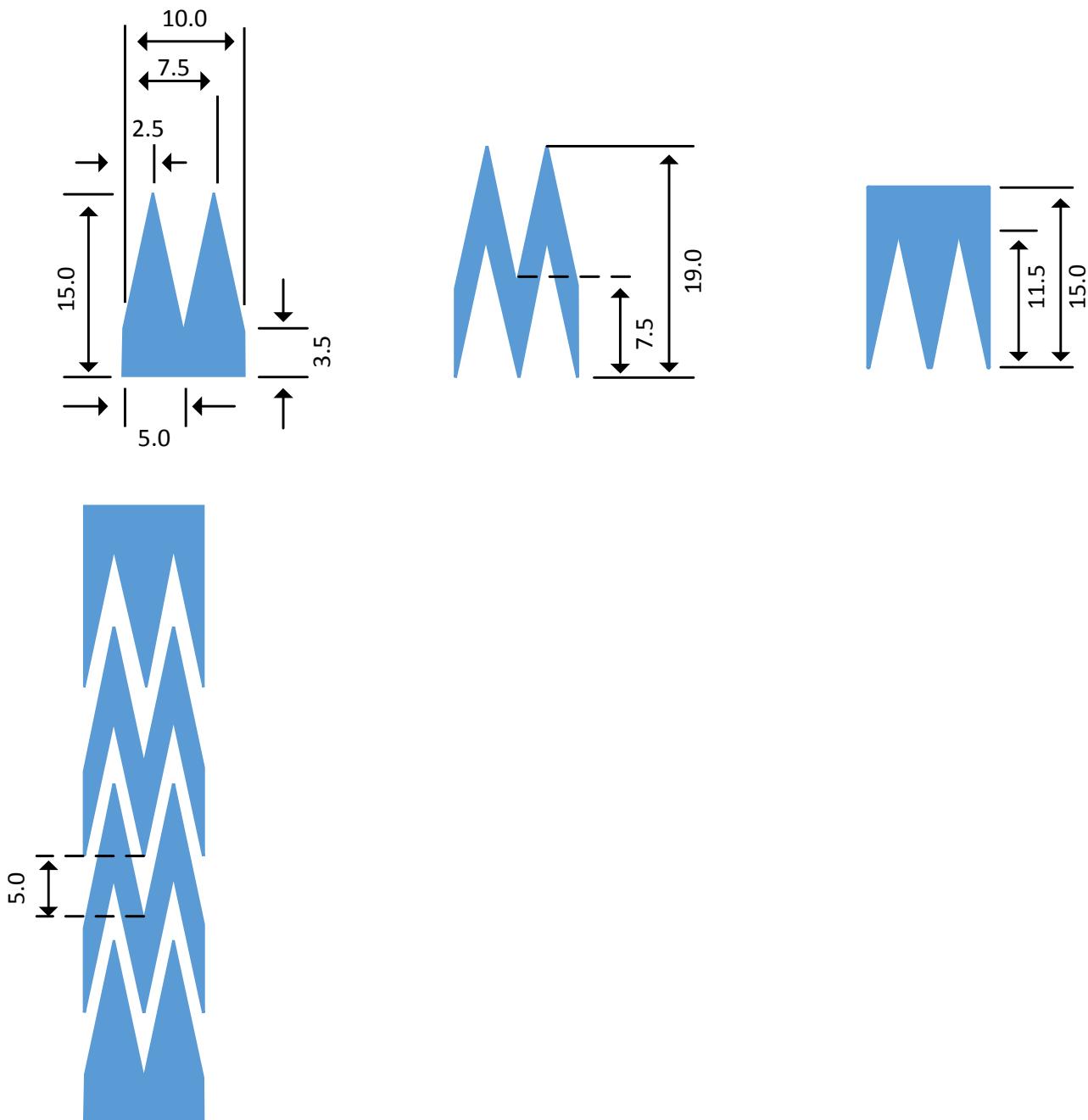
**Figure 4-2 the shapes of the electrode**

The recommended connection of the electrode to the MCU is to connect with as short a wiring as possible on the same board. When those two can't be mounted on the same board due to the form of the panel, alternative arrangements are shown in Figure 4-3.

**Figure 4-3 How to connect when board and electrode are widely separated**

(c) Constructing a slider

A slider can be constructed from the elements shown below. The "x" dimensions are all consistent with the dimensioning on the first element. The multiple elements are then stacked to create a slider with the desired number of elements



(d) Electrode's wiring

The wiring between the electrode and the Touchsensor (TS) port should be the shortest length possible. It is recommended to separate the trace from noisy signal lines such as PWM output and serial communications. If the sensor line must cross noisy signals it is recommended to cross them on opposite sides of the board and at a right angle as shown Figure 4-5. Figure 4-5 shows the parasitic capacitance and the resistance on the cap touch key board. The parasitic capacitance exists between the electrode, the electrode wiring, the connector and the GND pattern, the metal frame and the signal line. The maximum capacitance that CTSU can support is 50pF so the board and system design should control the parasitic capacitance so the total of the parasitic is 50pF or less. It is also recommended to design the board so the parasitic capacitance is at least 10 pF because small capacitances result in worse noise immunity. In addition, it is recommended to insert a damping resistance between the electrode and TS port to protect from surge breakdown and to improve the noise immunity. The impedance between the electrode and TS port effects the frequency of SCF and the sensitivity, therefore, the recommend the total resistance including the damping resistance is under 2Kohm.

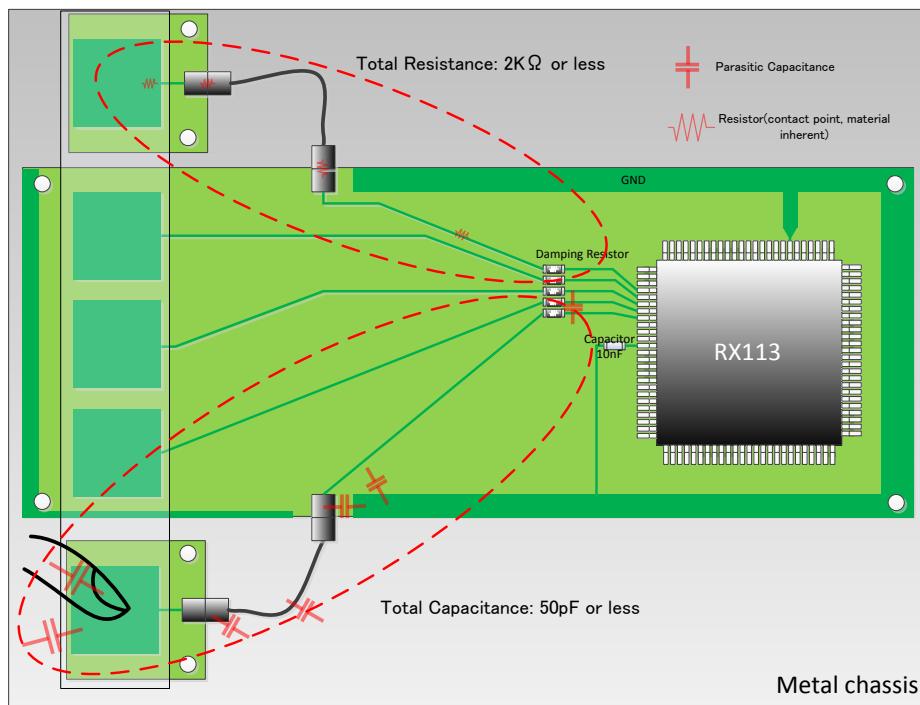


Figure 4-4 the parasitic capacitance and the resistance on the board

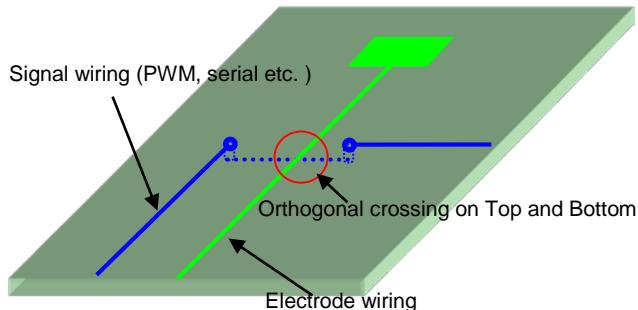


Figure 4-5 Wiring pattern

(e) GND shield for the electrode and it's wiring

A ground plane can be an effective measure against radiated and conducted noise. When using a ground plane a mesh ground pattern, as shown in Figure 4-6, is effective to decrease the parasitic capacitance.

(f) TSCAP port

It is necessary to insert 10nF capacitance between TS port and GND to act as low pass filter. This capacitance must be nearby TSCAP port and the wiring must be short as possible.

4.2.2 Design of the mutual-capacitance method Cap touch key board

(a) Outline

Capacitive touch detection by the mutual method utilizes the phenomenon that a part of capacitive field coupling between the mutual electrodes is diverted to ground by a material such as a human body as shown in Figure 1-1. When using the mutual method one electrode is driven as the transmitting electrode and the other is connected to the capacitance detector as the receiving electrode. The capacity detector measures the coupling of electric charge from one electrode to the other. If the conductive material comes closer the mutual electrode, a part of capacitive coupling is diverted into that object and the coupling to the receiving electrode is decreased. By periodically measuring the coupled field it is possible to detect a “touch”.

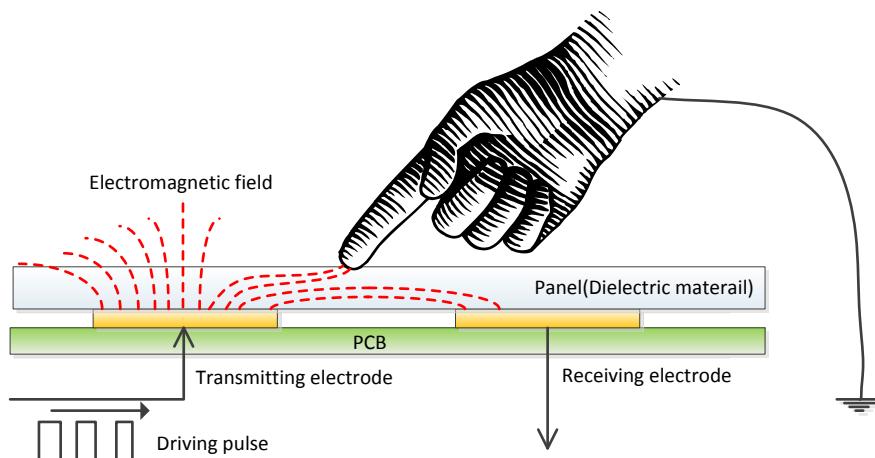


Figure 4-6 Basis of Mutual capacitance

The basis of Renesas mutual capacitance method is shown in Figure 1-2. The CTSU(Capacitive Touch Sensing Unit) is constructed using a capacitance-current convertor with SCF (Switched Capacitor Filter) and a current detector. The CTSU can represent any parasitic capacitance connected the external port of the MCU as a digital value. In addition, it includes a pulse generator synchronized with the SCF switching cycle and it is possible to measure the mutual capacitance of electrodes that are placed between SCF port and the pulse output port.

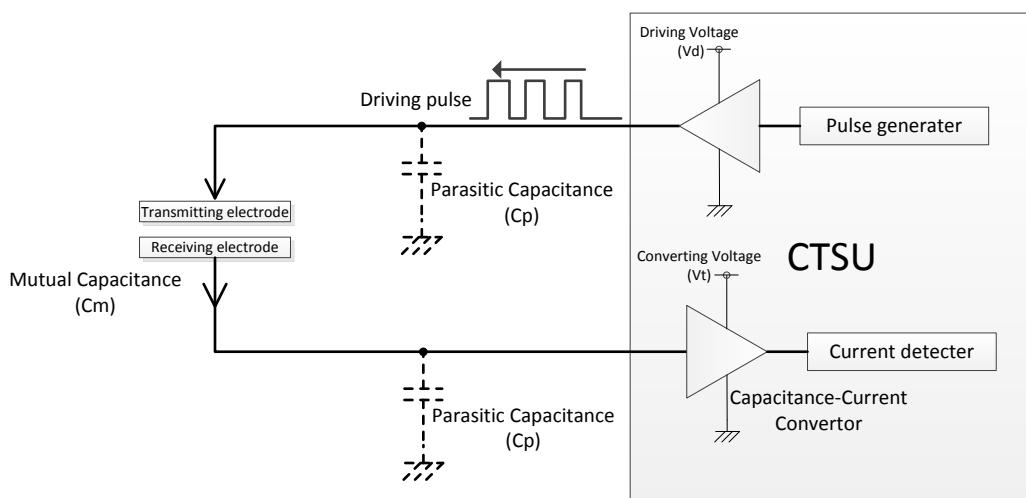


Figure 4-7 Renesas mutual capacitance method

In order to measure the capacitance C_m existing on the mutual electrode, the CTSU measures the mutual electrode's capacitance twice. The primary measurement measures the capacitance when SCF and the driving pulse are driven to

the same level, and secondly measurement occurs when the pulse is driven to the opposite level of the SCF. The C_m value is determined by subtracting the first measurement value from the secondly one. The formulas below show the relationship of the currents for the two measurements. These are based on the fundamental formula relating current, frequency and capacitance in a switched network with a constant voltage.

Basic Formula:

$$I_c = VFC$$

Where

I_c = Capacitor Current

F = Switching Frequency

C = capacitance

V = Switching Voltage

Mutual Capacitance Formulas:

$$I_{pri} = FCpVd + FCm(Vt - Vd) \quad \dots \dots \dots \text{Formula 4-1}$$

$$I_{sec} = FCpVd + FCm(Vt + Vd) \quad \dots \dots \dots \text{Formula 4-2}$$

Formula 4-2—Formula 4-1

$$\begin{aligned} &= I_{sec} - I_{pri} \\ &= FCpVd + FCm(Vt + Vd) - [FCpVd + FCm(Vt - Vd)] \\ &= 2FCmVd \quad \dots \dots \dots \text{Formula 4-3} \end{aligned}$$

I_{pri} = Primary current measurement value

I_{sec} = Secondly current measurement value

F = Frequency of SCF and Driving pulse

V_d = Voltage of the pulse generator circuit

V_t = Voltage of SCF driving

C_m = Capacitance existing between the electrodes

C_p = Parasitic capacitance of each electrode and its wiring

Formula 1-1 and Formula 1-2 show the current values resulting from the primary and secondary measurements. Formula 1-4 shows the subtraction the primary measurement from the second one. In the CTSU circuit F and V_d are constant values so C_m value can be calculated from Formula 1-5. Notice another benefit is the parasitic capacitance is cancelled in the result.

(b) Button design of the mutual capacitance method

Figure 2-1 shows the recommended pattern for a mutual button. The outside pattern is the transmitting electrode (Tx) and inside is the receiving electrode (Rx).

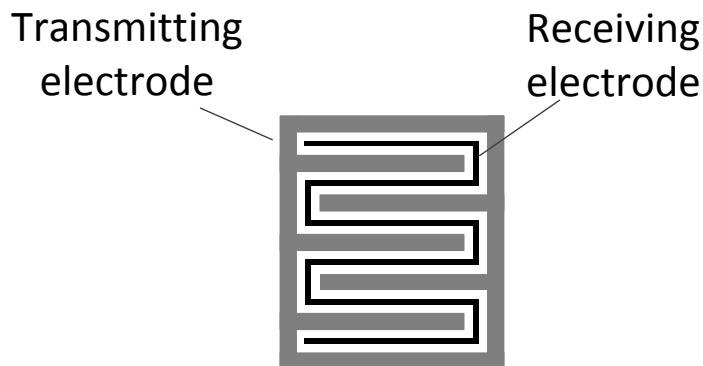


Figure 4-8 the sample of the button pattern by the mutual capacitance method

In order to increase the capacitance, the opposing areas of the transmit and receive surface should be kept large. The opposing surfaces form the plates of the coupling capacitance. The recommended area of the button is from 10x10 to 16x16 mm. It is possible to construct a button larger than 16 x16mm button but there will be little increase in the sensitivity of the mutual field influence and you have to consider the effect of the parasitic capacitance.

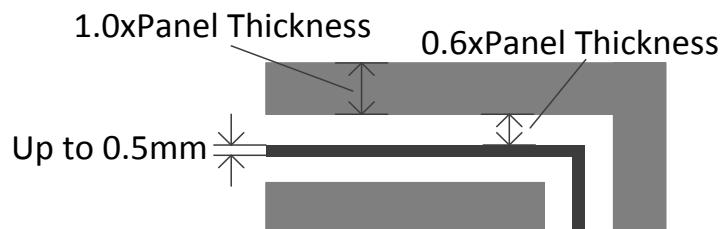


Figure 4-9 the electrode pattern width

Figure 2-2 shows the electrode pattern width. To reduce the parasitic capacitance, the width of Rx pattern is recommended less than 0.5mm. The actual width used depends on the resistance of the pattern material. When the material resistance is large (ex. Carbon film), the width will have to be increased to keep the resistance small. It is recommended to keep the Tx pattern the same thickness as the cover panel. The distance of Rx and Tx should be 0.6 x thickness of cover panel. If there is a conflict between these trace thicknesses and the parallel areas of the Rx and Tx surface the opposing area is a higher priority.

(c) Wiring

When sensing using the mutual method, the Rx trace layout is the most critical. Noise injection from other wirings and the parasitic capacitance with GND pattern can become problems. This section details examples of routing.

In order to prevent unanticipated capacitive coupling between Tx and Rx wiring, Tx and Rx wiring should be separated as far as they practical. At a minimum, the distance should be more than a finger touch distance as shown Figure 3-1. In addition, if Tx and Rx must cross it is recommended to wire orthogonal and to minimize any parallel traces as shown Figure 3-2.

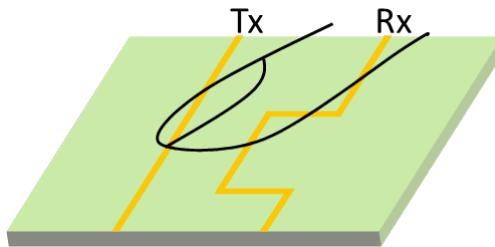


Figure 4-10 Tx and Rx wirings distance

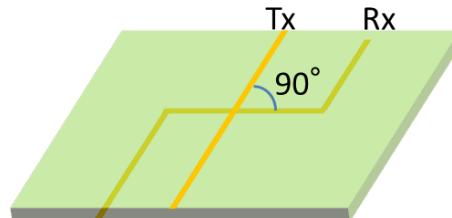


Figure 4-11 In case of crossing Tx and Rx wirings

The trace length from the Rx MCU port pin should be kept as short as possible to minimize the parasitic capacitance and series resistance. We recommend keeping the parasitic capacitance under 20pF and the resistance under 2Kohm as shown Figure 3-3.

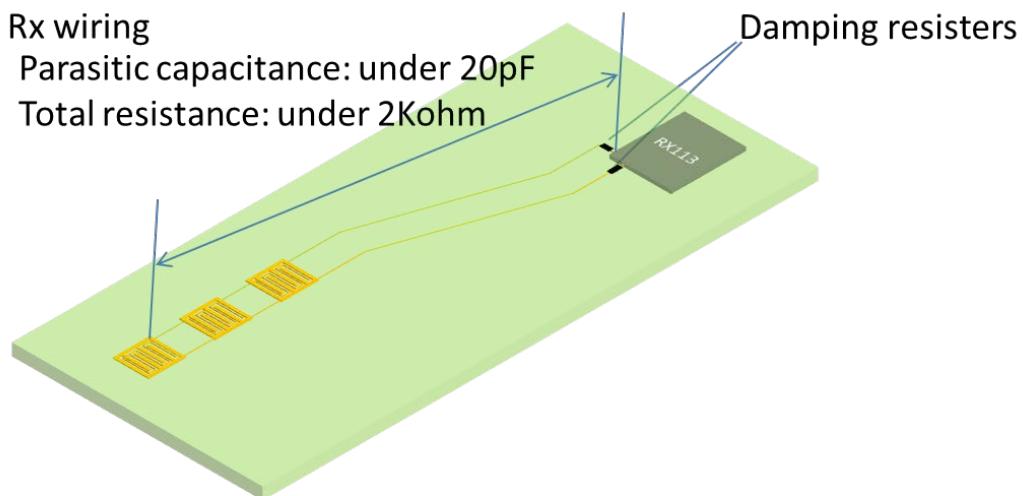


Figure 4-12 Parasitic capacitance and resistance of Rx wiring

4.3 CTSU register setting

The register configuration is typically performed by the Renesas supplied firmware driver and the user does not typically need to set these registers.

4.3.1 CTSU register setting for self-capacitance method

(1) Initialization

It is necessary to set the register initial value to measure the capacitance. Refer RX113 User's manual.

- TS port setting

- TSCAP port LPF discharge process
- CTSU initialize
- DTC setting for transmitting and receiving from/to RAM and CTSU registers

(2) The explanation of the measurement time of ICO counter

As discussed previously, the oscillation output of Sensor ICO & Reference ICO is counted by each Sensor ICO counter & Reference ICO counter during the measurement period, and these value are stored to the registers as the count values. This measurement period is set using the following register values and formula.

- IO driver base clock cycle:

It is determined by PCLK frequency input to CTSU, CTSU Count Source Select bit and CTSU Sensor Drive pulse Division Control bit. For example:

PCK =32MHz

CTSU Count Source Select bit = PCLK/2

CTSU Sensor Drive pulse Division Control bit = 1/32

The resulting IO driver base clock frequency is 0.5MHz (Cycle is 2uSec). The CTSU Sensor Drive pulse Division Control bit is configured for each TS port and written to the register DTC

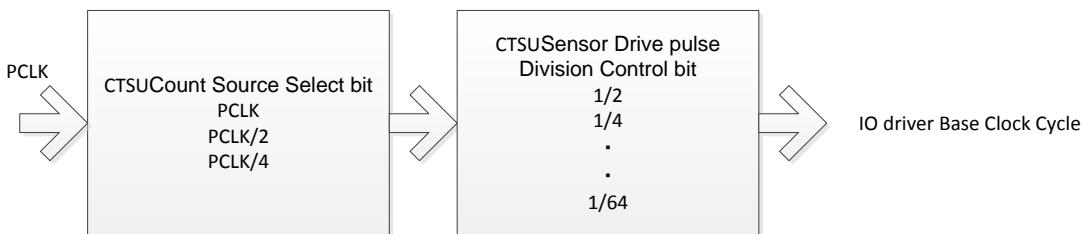


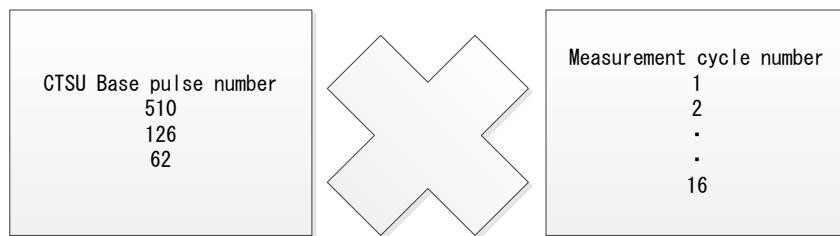
Figure 4-13 IO driver Base Clock Cycle

- Base pulse number:

This register configures the number of pulses to output from IO driver. This is 1 period of IO driver output randomized by the phase shifter

- Measurement cycle number

This is the number of times the base pulse pattern is repeated. It is determined by CTSUPRRATIO register setting. The Base Pulse number times the Measurement cycle number gives the number of pulses in one measurement



- Measurement number : This configures the number of times a measurement is repeated on a channel before the scan is considered complete. It is determined by CTSUSNUM register setting. It is possible to set the measurement number to each TS port by DTC transfer.

Measurement time (Sec) = IO driver base clock cycle × [Base pulse number × Measurement pulse number + (Base pulse number-2) × 0.25] × Measurement cycle number

Formula 4-6 Measurement time

These values determine not only the measurement time of ICO counters but also the measurement time of each TS port. The IO driver base clock cycle and measurement number are transferred by DTC, SCF frequency and the measurement period are changeable for each TS port. The IO driver base clock and the measurement period must be considered for each TS port individually since it is dependent on the parasitic capacitance and the resistance of each measurement port, it is also important to insure the Sensor ICO counter does not overflow. Figure 4-14 shows the relationship of IO driver output and ICO counter. In this example, it shows when CTSUSNUM register is set to measure twice, ICO counter count value becomes 0xFFFF as the result there is an overflow and it is impossible to get a correct measurement value. When ICO counter overflows, the measurement value is fixed 0xFFFF and CTSUSOVF (Sensor ICO counter overflow flag) or/and CTSUROVF (Reference ICO counter overflow flag) are set "1". These flags must be cleared manually.

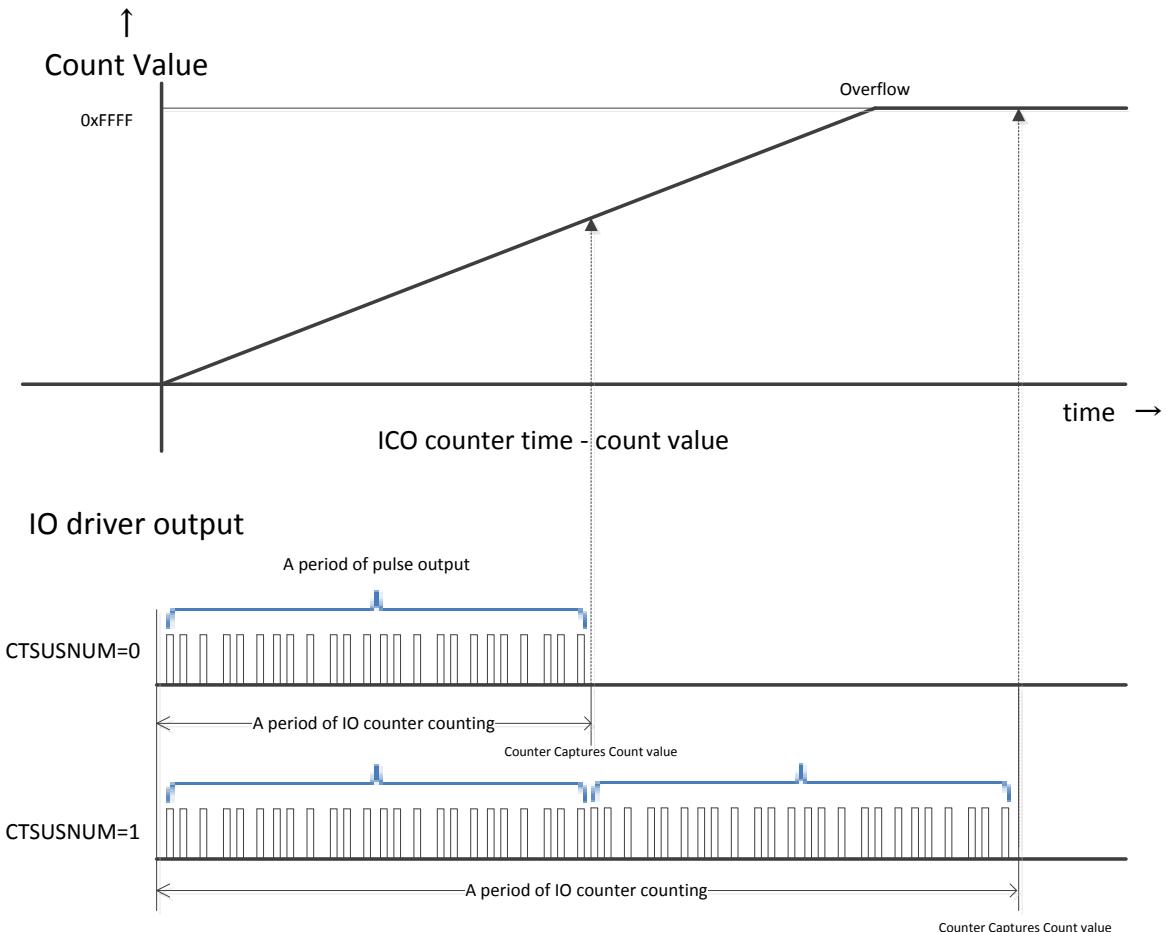


Figure 4-15 the relation example of IO driver output and ICO counter

(3) Determination of IO driver frequency

As it is described above, IO driver frequency is a key parameter in determining the measurement sensitivity of capacitance by the CTSU. If the frequency is faster than the capacitance can charge & discharge the reading will be incorrect. In addition to the capacitance that must be driven it is important to consider the resistance between the electrode and TS port since it will affect the capacitance charge & discharge time.

If the resistance is already established, the approximate parasitic capacitance of the cap touch key board can be measured by CTSU using the following method.

First the sensor ICO count value is measured by CTSU. In this case, CTSU register values are as follows;

- IO driver baseclock:0.5MHz

Example If PCLK=32MHz, CTSUCLK=00B、CTSUSDP=31

- CTSUATUNE0: If $V_{CC} \geq 2.4V$ then "0" else "1"

- CTSUATINE1: 1 High output
- CTSUPRRATIO: 3 Recommend parameter
- CTSUPRMODE: 10B Base pulse number 62
- CTSUSOFF: 1 High frequency range noise immunity OFF
- CTSUSO:00000000B No sensor ICO offset
- CTSUSNUM:0 Measurement number once

The approximate parasitic capacitance connected each TS port is determined using values in Table 4-2. If the parasitic capacitance from the table is under 9pF or over 50pF, there may not be enough sensitivity for a robust system. In this case, a modification to the layout should be considered, or in the case of too little capacitance a small capacitor can be added to the port connection.

- Under 9pF

The capacity coupling between the electrode and GND is very small and noise immunity may be degraded,

- Over 50pF

The current required to drive the capacitance is beyond CTSU design capacity

Table 4-2 Table of the approximate parasitic capacitance and Sensor ICO count value

Sensor ICO count value	Capacitance (pF)
9801 or under	Under 9
9800-10200	Approximately 10
10201-11000	Approximately 12
11001-11900	Approximately 15
11901-13000	Approximately 18
13001-14600	Approximately 22
14601-16200	Approximately 27
16201-18000	Approximately 33
18001-19600	Approximately 39
19601-20300	Approximately 47
20301 or over	Over 50

*Sensor ICO count is the actual value measured by RX113 sample chip

IO driver frequency gains with using the approximate capacitance and the resistance value (Table 4-3).

RXE	0%~90% 電圧立ち上がり時間																											
	200	220	240	270	300	320	350	380	400	470	510	560	620	680	750	820	910	1000	1100	1200	1300	1500	1600	1800	2000	2700		
0	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98			
5	19.65	19.87	14.07	14.43	14.72	15.10	15.45	15.95	16.30	16.78	17.25	18.02	18.83	19.64	20.60	21.53	22.82	24.19	25.53	26.92	28.35	31.19	32.63	35.81	41.40			
10	37.27	37.85	37.97	37.95	37.95	37.95	37.95	37.95	37.95	37.95	37.95	37.95	37.95	37.95	37.95	37.95	37.95	37.95	37.95	37.95	37.95	37.95	37.95	37.95	37.95			
15	61.08	61.84	32.69	33.88	34.05	34.05	34.05	34.05	34.05	34.05	34.05	34.05	34.05	34.05	34.05	34.05	34.05	34.05	34.05	34.05	34.05	34.05	34.05	34.05	34.05			
20	98.45	97.07	30.81	30.81	30.74	41.16	42.53	44.00	45.69	47.60	49.57	51.83	54.25	57.88	60.41	64.26	68.13	72.74	77.76	88.18	80.43	93.70	104.89	110.03	116.20	119.50		
25	44.38	45.42	46.69	48.91	49.29	52.19	54.03	56.92	58.49	61.12	61.63	64.04	67.04	71.09	74.78	79.81	84.34	90.38	98.38	108.47	110.27	117.00	130.89	137.23	161.01	174.92	178.09	
30	62.20	53.72	55.18	57.22	59.39	51.80	53.97	55.43	56.93	57.42	57.92	58.33	59.33	59.33	59.33	59.33	59.33	59.33	59.33	59.33	59.33	59.33	59.33	59.33	59.33	59.33		
35	92.27	89.48	89.25	89.25	89.25	87.45	87.45	86.78	86.80	87.25	87.25	87.63	87.63	87.63	87.63	87.63	87.63	87.63	87.63	87.63	87.63	87.63	87.63	87.63	87.63	87.63		
40	108.89	111.89	119.09	129.11	129.92	130.92	139.92	140.27	147.24	144.12	161.29	169.57	180.41	190.83	203.28	218.94	231.36	241.87	264.77	282.36	297.97	313.10	327.83	347.83	423.53	456.92		
45	130.26	134.39	138.31	144.16	160.31	156.14	163.23	168.63	176.82	185.12	193.90	203.97	216.84	229.28	244.09	259.04	277.92	297.28	316.08	339.78	360.99	379.44	409.86	478.71	509.28	565.79	604.74	666.81
50	184.69	189.16	183.99	171.08	179.93	171.93	195.76	199.88	209.89	219.85	229.99	242.12	267.43	271.89	299.08	307.89	330.74	352.26	378.47	409.86	479.09	509.28	565.79	604.74	666.81			

Table 4-3 the relation of Sensor ICO frequency with the measured capacitance and the resistance

(4) Trimming of Sensor ICO

Sensor ICO is a current oscillator and the amount of input current determines its frequency. The linear specification of frequency with the input current is up to approximately 100MHz. The linearity of the frequency response is lost at over 100MHz and at very low frequencies (Shown the upper left of Figure 4-9). The characteristic of frequency and current also varied among individual chips. In order to compensate for variation in each by each chip a Reference ICO is used. The characteristics of Sensor ICO and Reference ICO are well matched since they have same basic construction and are on the same die. The Sensor ICO is driven by the current that is generated by the IO driver and TSCAP voltage, the Reference ICO is driven by the current that is generated and controlled by a register setting (0-19.5uA). The linear range of the Reference ICO is shown the upper right of Figure 4-9, this region corresponds to register value between 0x03FF and 0x0FFF (It shown blue line circled area in Figure 4-9).

Since the Sensor ICO frequency is determined the current supplied by IO driver to the external capacitance will often exceed the linear range of the ICO. (Refer the lower left of Figure 4-9). To prevent the ICO current going outside the linear range of ICO a current offset function is used. This offset current supplies a portion of the current required to drive the external capacitance to reduce the ICO measured current back into the linear range (Refer the lower right of Figure 4-9). The CTSUSO & CTSURIOA registers are used for trimming the current. The process is to first write 0x3FF to CTSURIOA which will set the current supplied to the Reference ICO to approximately 5uA. The 5 uA value is used because it is at the lower end of the linear range of the ICO. The second step is to measure Reference ICO count value. Finally the value of the CTSUSO register is modified until Sensor ICO count and Reference ICO become the same value, this means the Sensor ICO is driving 5 uA of the external capacitive load. This places it at the lower end of the linear range so there is maximum range for driving additional capacitance. It also provides enough margin so the measurement current does not drop down into the lower non-linear region. It is possible to offset the current about 100uA. Since the ICO frequency specification is different with each chip it is recommended that trimming is done on each device. This offset process is done automatically by the Renesas driver on initialization and periodically during operation.

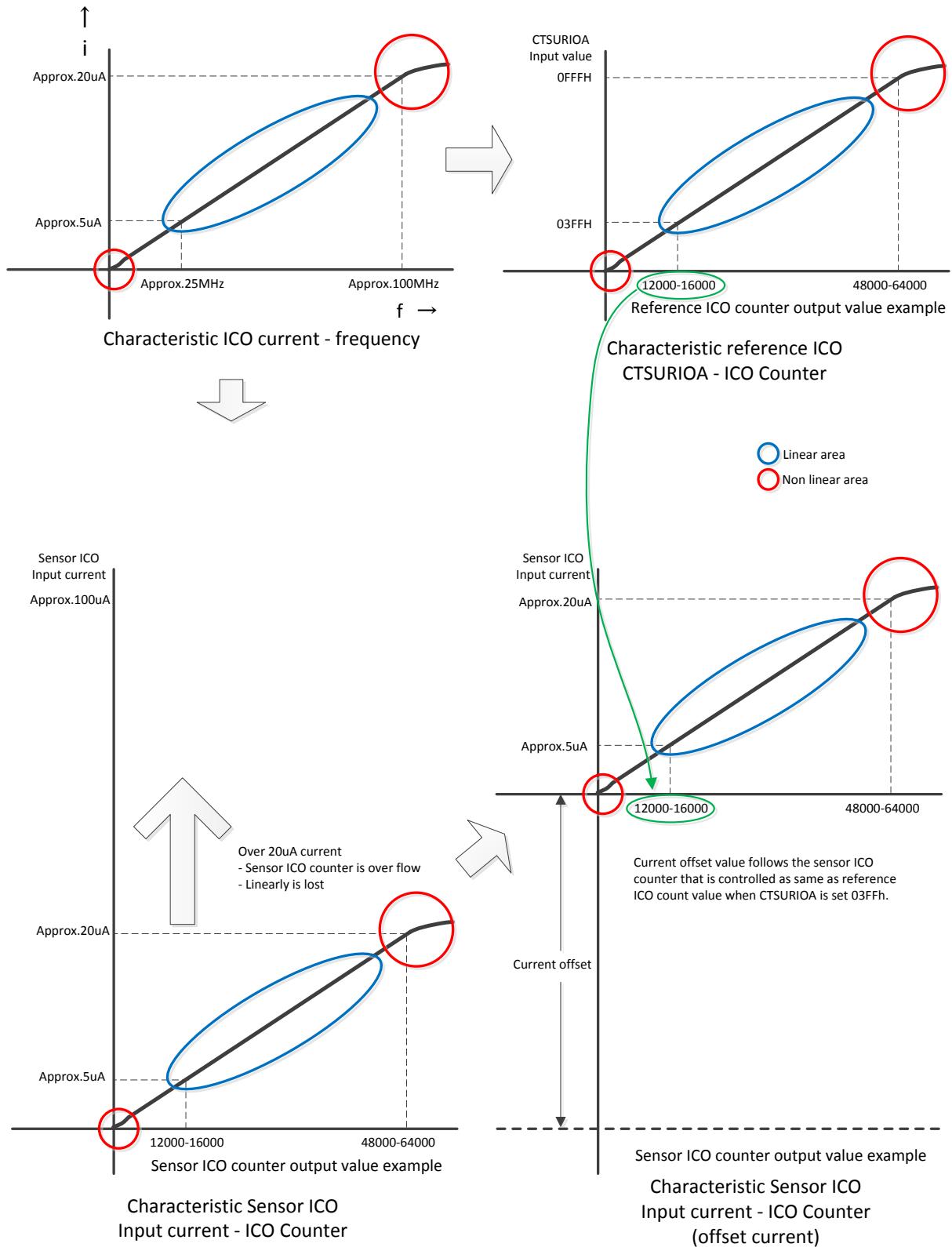


Figure 4-16 the relation of Sensor ICO, reference ICO and the current

(5) Sensor ICO underflow

If the configured offset current is greater than that required by the IO driver an underflow of Sensor ICO will occur. In this situation, Sensor ICO count value becomes unstable and incorrect. This condition also results in an incorrect

TSCAP voltage and the TSCAP voltage error monitoring bit (CTSUICOMP) will be set. When the CTSUICOMP bit is set “1” further measurements should be stopped and the offset value each TS port should be verified. Hardware failures, like open or shorted sensor lines, can also result in the CTSUICOMP bit being set.

4.3.2 CTSU register setting for mutual-capacitance method

(a) Initialize

Initialization of the registers is the same as the initialization of the self-capacitance method except it must also configure the which electrodes are TX and which are RX.

(b) The measurement period

As shown the captor 4.2.2, the measurement period of the mutual-capacitance method is twice as long as the measurement period of the self-capacitance method because the mutual-capacitance method measures the capacitance twice each electrode.

(c) Determine of IO driver (SCF) frequency

As same as the self-capacitance method, it is determined by the measurement of approximately capacitance.

4.4 Firmware process

4.4.1 Firmware process of self-capacitance method

(a) Measurement process

The Cap touch process continuously measures the capacitance continuously and is judges whether the keys are ON or OFF by the change in the capacitance value. It is necessary that Cap touch process runs at a periodic rate. The CTSU measures the selected TS ports and transfers the result of the measurement from the Registers of Sensor ICO counter and Reference ICO counter to RAM via DTC. The firmware process initiates the CTSU scan then once the CTSU measurement end (CTSUFN) interrupt occurs the firmware reads the results in RAM and processes the data to determine key ON or OFF status. The measurement period of the each TS port is approximately 500uSEC. For example if 10 TS port are used for key, it takes approximately 5mSEC to detect 10 keys.

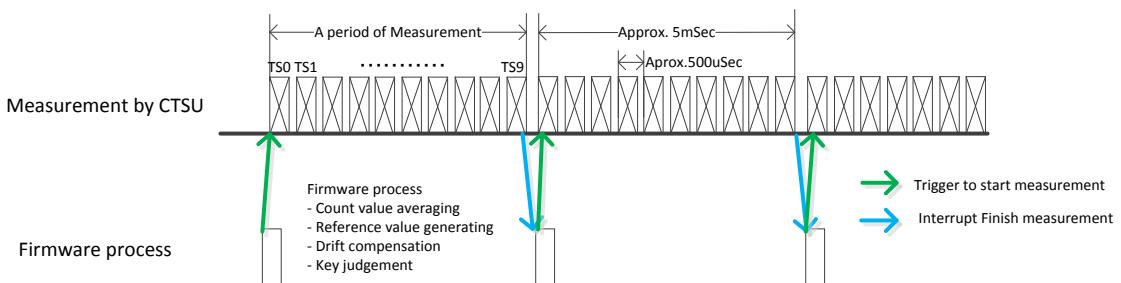


Figure 4-17 the timing diagram of CTSU and Firmware process

(b) Generating the reference value and the threshold value

Cap touch key is different from the mechanical switch key and there is not clear status of ON or OFF as same as the mechanical switch. It is judged by the change of the counts (capacitance) when touch occurs. The firmware maintains a long term average value of the counts, which is called the reference value. The reference value is compared to the last scan value and if the difference is greater than a configured delta, referred to as the threshold, the firmware judges key “ON”. The reference values is updated at a specified rate to compensate for environmental changes, this compensation is referred to as “drift compensation”. The compensation rate is user configurable but is typically every 2-3 seconds. The scan values are filtered by a running average filter so key response time can be changed by modifying the number of averaging and its speed. Cap touch key’s sensitivity can be changed by changing the threshold value. Drift compensation updates are held off while a key is judged to be touched so a pressed key does not “turn off” due to the drift compensation setting the reference equal to the touched value (Refer Figure 4-18).

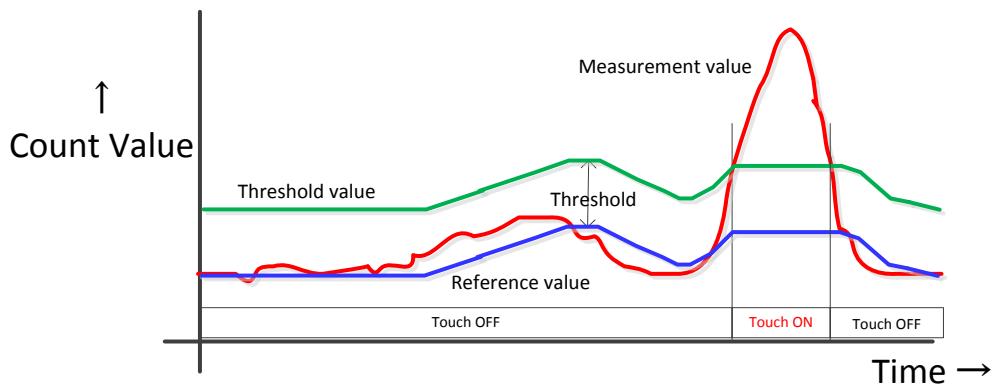


Figure 4-18 Measurement value, Reference value and Threshold value

(c) Tuning of the firmware parameters

Tuning parameters of the standard firmware are shown below.

- Continual touch limiter

There is a possibility that the key status of “ON” never changes due to injecting noise or the very sudden change in the parasitic capacitance. The drift correction process can not follow these fast phenomenon and once the condition occurs drift compensation is disabled. To return the normal status, if the key ON period exceeds a configurable time that key is turned OFF and the drift correction process can correct for the condition. This feature is called Continual touch limiter.

User can change the following parameters;

Continual touch limiter process ON or OFF

- Drift correction
- Multi touch cancel
- Response delay time to touch/non-touch
- Hysteresis
- Threshold

5. Noise Immunity

5.1 Overview

Capacitive touch switches need to be designed so they are not affected adversely by noise or power supply variation which can result in changes to the count readings.

In addition to various types of noise immunity mechanisms incorporated in CTSU software filters are used in the Renesas capacitive touch solution. High noise immunity should also be a key design consideration for the user board. These noise immunities are explained in this chapter.

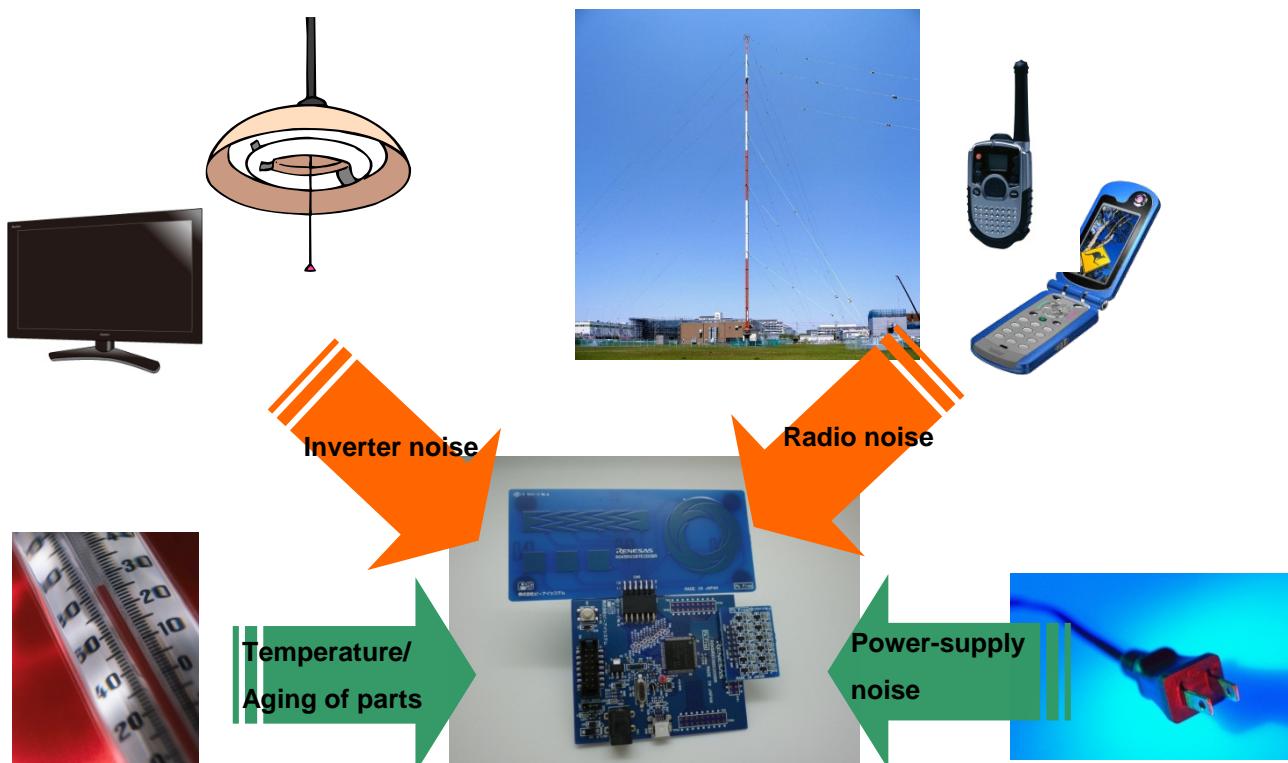


Figure 5-1 Disturbance factors to affect the touch measurement

5.2 Noise Immunity on the Board

5.2.1 Power Supply Circuit

The stability of the power supply to the MCU is a key component in noise rejection. Following is the precautions and measures.

(a) Using 3 terminal regulator

We recommend using 3 terminal regulator in order to remove ripple component of power supply.

(b) Peripheral ports of the port used for the touch measurement

Port pins that are part of a port output group that has touch capability but are being used for other functions should not be utilized for high speed, high current operations such as PWM drive of LED, sound output, and serial communication. High current switching on ports where a TX port of a mutual configuration are sensitive to internal Vcc variations due to high current demands which drop the drive Vcc and result in a touch measurement that is unstable.

(c) Inserting the Ferrite Core

If the conducted noise from the power supply line or human body is assumed, it is recommended to insert a ferrite core to the power supply line.

(d) Separation of Power

When sharing the power with other devices, it is recommended to isolate the touch MCU power from other switching loads on the same source to minimize the impact on touch detection.

5.1.2 Touch Electrode and Wiring

Since the touch electrode and wiring act as an antenna the following measures are required to maximize electromagnetic noise immunity and emmissions

(a) Wiring

The distance of wiring between touch electrode and touch measurement port should be as short as possible. Also capacitive coupling of high speed signal lines can result in noise superimposed on touch sensing wire if traces run parallel with the high speed signal lines.

(b) Position of GND Pattern

Improved noise immunity is often achieved by placing a GND pattern in the vicinity of touch electrode and wiring as an electromagnetic shield. However, when placing GND, set the GND pattern as mesh with approximately 3 to 7 copper - space ratio, this provides improved immunity but minimizes the effect on touch sensitivity due to of parasitic capacitance.

(c) ESD Protection

The touch overlay panel typically provides ESD protection so it is recommended to ensure adequate breakdown-resistant for assumed electrostatic strength. Also, care should be taken not to generate a gap in the panel joint since there is a possibility that the static electricity can “sneak” through the gap,



Figure 5-2 Cases where static electricity sneaks from the gap of the cover panel

5.2 Software

Following is the example of software filters

5.2.1 Drift Correction Process

The capacitive touch measurement is influenced by environmental changes such as temperature, humidity, and aging of member. These gradual changes are compensated for using the drift compensation process shown in Figure 5-6. As mentioned above, threshold value above which a touch is determined to occur is calculated from the reference value. This reference value is periodically updated to compensate for environmental changes, the compensation is held off when a touch has been determined. The update rate of the reference value is configurable. If it is too fast the reference may react as a finger is approaching and start to compensate which may result in loss of touch sensitivity. If it is very slow false touches may occur due to changes in environmental conditions.

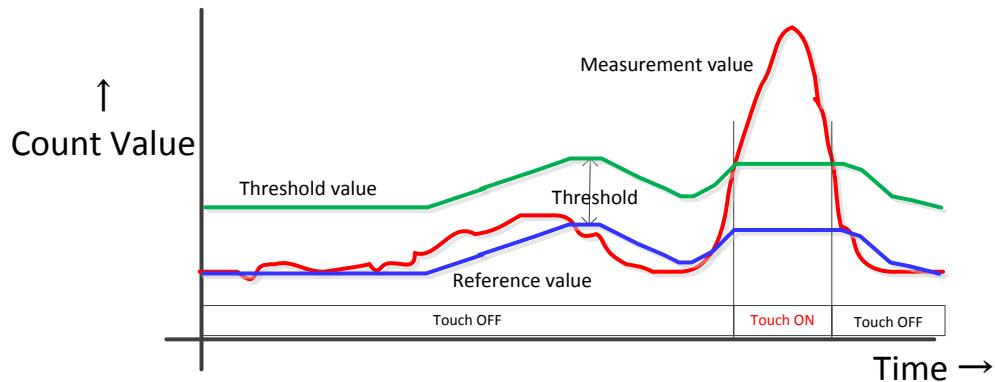


Figure 5-3 Drift Correction Processing

5.2.2 Countermeasure of Random Noise

Software filters are also used to compensate for random or electromagnetic noise. The following is the example of software filter.

(a) Moving Average Filter

The Renesas solution utilizes a moving average filter as described in figure 5-7. In the example, the measurement averages the last 4 values. Moving average filters provide Adjusting the number samples averaged can improve rejection of pulses but does increase the response time for a touch

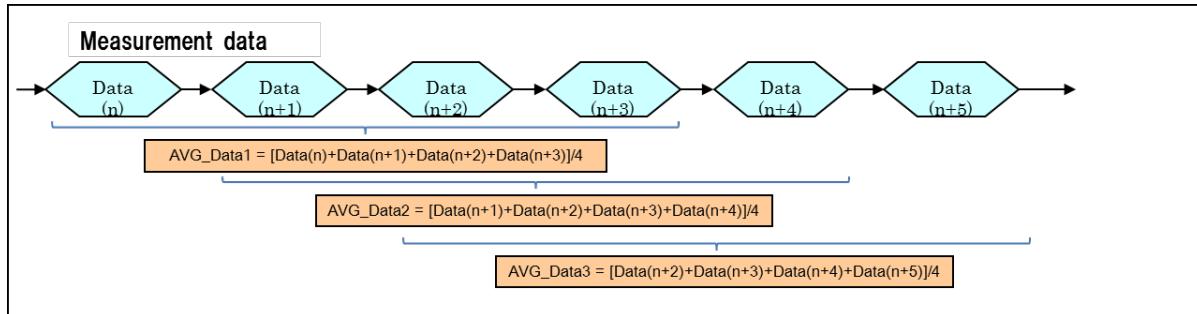


Figure 5-4 Example of Moving Average Filter

(b) Upper Limit Filter

The upper limit filter compares the previous and latest measurement value limits the change in the output to an upper limit. Figure 5-8 shows the example of Upper Limit Filter. If there is a difference of more than +/- 20 the count value is limited +/- 20. As shown the graph, the filter suppress the sudden change of count value and keeps the judgment of touch On or OFF correctly..

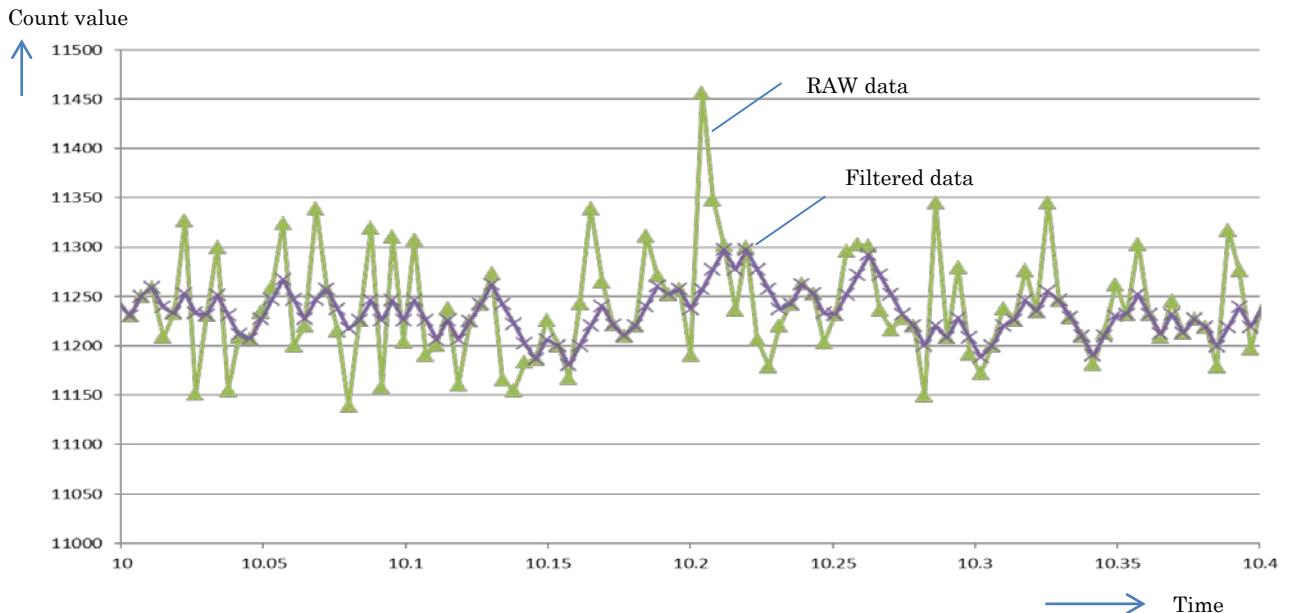


Figure 5-5 Example of Upper Limit Filter

5.2.3 Debounce Filter

Similar to a mechanical key, it is desirable to use a “debounce” filter for cap touch key to reduce the occurrence of false touches due to noise transients. It is not actually a debounce filter since touch sensors do not bounce but it performs a similar function

Some example shows below.

(a) Confirming correspondence with N times

This process requires the configured number of same key states (On or OFF) to occur before the output state changes. Basically when a state change is detected subsequent scans are compared, if the state is the same a counter is incremented. If the counter reaches the configured value then the output state is changed. If the opposite state is

encountered once the sequence starts the counter is set to zero. Increasing the count value improves rejection but creates delayed response to state changes

(b) Decision by majority

This process decides whether a key is ON or OFF by taking the majority of the detected states during a fixed period. It is faster than the process Confirming correspondence with N times, but the canceling of the debounce effect is weaker than above.

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Revision History

Rev.	Date	Page	Description
			Summary

General Precautions in the Handling of MPU/MCU Products

The following usage notes are applicable to all MPU/MCU products from Renesas. For detailed usage notes on the products covered by this document, refer to the relevant sections of the document as well as any technical updates that have been issued for the products.

1. Handling of Unused Pins

Handle unused pins in accordance with the directions given under Handling of Unused Pins in the manual.

- The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible. Unused pins should be handled as described under Handling of Unused Pins in the manual.

2. Processing at Power-on

The state of the product is undefined at the moment when power is supplied.

- The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the moment when power is supplied.

In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the moment when power is supplied until the reset process is completed.

In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the moment when power is supplied until the power reaches the level at which resetting has been specified.

3. Prohibition of Access to Reserved Addresses

Access to reserved addresses is prohibited.

- The reserved addresses are provided for the possible future expansion of functions. Do not access these addresses; the correct operation of LSI is not guaranteed if they are accessed.

4. Clock Signals

After applying a reset, only release the reset line after the operating clock signal has become stable. When switching the clock signal during program execution, wait until the target clock signal has stabilized.

- When the clock signal is generated with an external resonator (or from an external oscillator) during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Moreover, when switching to a clock signal produced with an external resonator (or by an external oscillator) while program execution is in progress, wait until the target clock signal is stable.

5. Differences between Products

Before changing from one product to another, i.e. to a product with a different part number, confirm that the change will not lead to problems.

- The characteristics of an MPU or MCU in the same group but having a different part number may differ in terms of the internal memory capacity, layout pattern, and other factors, which can affect the ranges of electrical characteristics, such as characteristic values, operating margins, immunity to noise, and amount of radiated noise. When changing to a product with a different part number, implement a system-evaluation test for the given product.

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